NOTES

ON THE

Rocks and Minerals of Michigan

TO ACCOMPANY THE

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INTRODUCTION

Definition of Geology.

Geology is an historical science. Its object is to give a complete history of the earth from the time of its formation as a separate planet down to its present state. It teaches that the earth is an everchanging mass which, like the marble under the chisel of the sculptor, has been shaped and modeled by the master hand of nature until it has attained its present state of perfection. Geology traces the development of all animal life from the earliest, simplest forms to the highly complicated ones of the present age; it considers the formation of existing rocks, their relations one to another, and their past history.

Analogy between History and Geology.

Students of history in the ordinary sense of the word—history of mankind—obtain their knowledge from the old documents and monuments handed down to us by our forerunners. The historian combines the facts which he gleans in various ways and thus forms a more or less correct idea of the life, customs and state of civilization of our ancestors. The greater the number of facts known of a certain period the greater the probability of forming a true picture of that period.

The geologist has a similar task. The earth itself furnishes the documents. The changes through which it has passed have left their impressions, which may still be seen in the earth's crust. The geologist tries to interpret these records of the past, that is, to infer the changes and to decide what agencies acted to produce them. To aid

in this interpretation he also studies the changes now going on and observes the kinds of records which they are making. "The present is the key to the past." The materials of which the earth's crust consists are constantly changing, passing from one state to another, from a condition of unstable to one of more stable equilibrium, under the existing physical conditions. All rocks undergo modification and crumble away, and new rocks are formed from their loose disintegrated products.

Subdivisions of Geology.

Geology examines the rocks themselves from several different standpoints. (1) It treats of the materials of which the crust consists, their composition, their texture, their mode of occurrence and their products of alteration (the science of rocks or petrology). (2) It views the rock masses in their relations one to another as they occur in nature (structural and stratigraphical geology). (3) It considers the forces at work producing changes in the rocks themselves and their relative position one to another (dynamical geology). (4) It embraces the description and classification of all animal life whose remains are found preserved as fossils in the various kinds of rocks (palaeontology).

Object.

The object of this description is not to give a complete account of the geology of Michigan but only to sketch its general outlines. Similarly the aim of the accompanying collection is not to exhibit a full set of all known rocks and minerals occurring in Michigan, but rather to show a few of the most common ones picked out here and there, which best present a general idea of how rocks and minerals occur and of the bearing of their occurrence on the geology of the state.

CHAPTER 1.

GENERAL CHARACTERS OF MINERALS.

A few general remarks concerning minerals and rocks and the relations they bear one to another may aid in rendering the detailed description of the specimens in the collection more readily intelligible and also serve as a brief introduction to their study.

Definition of a Mineral Crystal Form.

A mineral is an inorganic, homogeneous, solid or viscous body found in the earth's crust.

Most minerals on forming assume some definite shape (crystal form) and if not broken are bounded by plane faces. Each mineral has its own peculiar type of figure. Thus Fig. 10 represents the usual type of quartz, Fig. 3 that of calcite, Fig. 8 that of analcite, Fig 4 that of barite, etc.

Constancy of Angle between two given Crystal Faces.

The angle which any two definite crystal planes or faces on a given mineral make with one another is constant for that mineral. In Fig. 10 the angle which the face or plane r makes with the face marked m is always 141° 47′. This is true for any crystal of quartz found

in any region and is a characteristic angle for quartz alone. It is not shown by any other known mineral of similar crystal form. Thus if we measure the angle between r and m on a mineral of the same general aspect of Fig. 10 and find it to be 141° 47′ the mineral is quartz. Hence we are able to use the "crystal form" as one of the distinguishing features for minerals.

Cohesion.

The various phenomena of cohesion in minerals as hardness, tenacity, cleavage and fracture are other important characteristics which are also employed in the practical determination of minerals. Like crystal form they result from the action of crystalline forces between the homogeneous particles constituting the mineral and may all be considered as pertaining to the power of resisting efforts to separate one part from another.

Hardness.

Specimen No. 36 is so soft that it can be scratched with the finger nail while on specimen No. 32 (quartz) not even the hardest knife makes an impression. The softest minerals, as talc, are said to have the hardness 1; other moderately soft H,2 (easily scratched with the finger nail); others soft with H,3 can hardly be scratched with the finger nail, if at all. Minerals with H,4, 5 or 6 may be scratched with a knife blade but with increasing difficulty, while on those with H,7 and above, steel makes no impression. A harder body will always scratch a softer one. The hardest known substance, diamond, H,10, will scratch any other substance. Diamonds must be ground and polished with diamond dust as softer substances have but very little effect on them.

Tenacity.

The tenacity of a mineral is observed by attempting to cut it. Under the knife a brittle mineral chips off and breaks up into powder, specimen No. 37 (barite). A sectile one cuts into slices but powders under a hammer, specimen No. 36 (gypsum). A malleable one cuts off in pieces but flattens out under the hammer and does not powder, specimen No. 16 (copper). A flexible mineral bends under pressure but does not return to its original position after the pressure is released, specimen No. 35 (gypsum), as is the case with an elastic mineral, specimen No. 33 (mica). The mineral pyrite, specimen No. 7 (called fool's gold), which is yellow and resembles gold to a certain extent may be easily separated from the latter by observing that it is hard and brittle and not soft and malleable as gold.

Fracture.

Minerals when broken exhibit several different kinds of surfaces of fracture. A mineral which breaks with a wavy, mussel-shell like surface, is said to have conchoidal fracture, specimen No. 29; one with a smooth surface an even fracture; one with a rugged surface with small elevations and depressions, an uneven fracture, specimen No. 3. An uneven fracture is said to be hackly, if elevations are sharp, toothed and bent, as broken iron, and splintery if the surface of fracture is covered with small wedge-like splinters. A mineral with earthy fracture shows only fine particles on its broken surface.

Cleavage.

Certain minerals separate more easily in one direction than in another, as wood splits more readily with the grain than across it. The property of splitting along

parallel flat planes is known as cleavage and is a marked feature of many minerals. If specimen No. 25 be struck a sharp blow with the hammer it will cleave up into small fragments all of the same shape as that illustrated in Fig. 7. This tendency to cleave along certain planes is due to the different forces of cohesion in the mineral. The crystal particles attract one another more strongly parallel to the plane of cleavage than perpendicular to it. The facility with which cleavage on a mineral is produced is known as the degree of cleavage. Planes of cleavage are always parallel to possible crystal faces. This property of cleavage is made use of in the preparation of mica flakes—popularly known as eisen-glass—for the windows of coal stoves. Were it not for the fact that diamonds cleave readily after a certain form they would be much more expensive than they are at present.

Lustre of Minerals.

Specimen No. 7 has the appearance of a metal. We express this resemblance by the term "metallic lustre." Specimen No. 31 (quartz) has no such "metallic lustre," but resembles glass and has glassy or vitreous lustre. Minerals are thus divided into different groups according to the lustre they present. The several types of lustre are (1) metallic (always opaque) specimen No. 7; (2) sub-metallic, specimen No. 1; (3) non-metallic. The lustre of non-metallic minerals is further classified as adamantine; glassy or vitreous, specimen No. 31; resinous, specimen No. 39; pearly, specimen No. 35 (*i. e.*, their lustre is similar to that of a diamond, of glass, of pitch, or of an iridescent pearl). There are also different degrees of lustre, as dull, shining, glistening, splendent, etc.

Color and Streak.

The color of minerals, especially in a powdered condition, is also used as a means of distinguishing one from another. Certain minerals are red, others yellow, etc., through all colors. The natural color of a mineral is designated as such, while its color in a powdered state is known as its streak. The usual way to obtain the color of a mineral in a powdered condition (its streak) is to draw it across a thin rough porcelain slate, whereupon it leaves its mark or streak as a pencil point does on a sheet of paper. Graphite in a powdered condition is black; a pencil therefore streaks or writes black. Specimen No. 1 streaks red, No. 2 yellow, etc.

Specific Gravity.

The specific gravity (sp. gr.) of minerals and rocks is one of their most useful constants. The relative specific gravity of two minerals is readily detected by balancing the two, one in each hand and at the same time making allowance for difference in size.

Formation of Minerals.

Minerals are formed in various ways. (a) They may be deposited out of solution as salt is precipitated by the evaporation of salt water; (b) or formed on the cooling and solidification of a hot, fused or molten mass, as lava. A familiar example of this mode of formation of crystals is that of the "sugaring" of candy when it crystallizes out as minute crystals instead of cooling to a clear glass-like wax. (c) Other minerals result from the chemical action of gases and vapors one on another or on other minerals (formation of tin ores, weathering products of

minerals), and (d) still others from great pressure and heat which brings the crystal particles so close one to another that the crystalline forces may act and thus produce crystals.

Association of Minerals.

As a result of the different modes of formation of minerals, each mineral is found associated only with a limited number of other minerals. Practical experience has shown that fixed laws relating to the association of minerals may be established which are of prime importance to the mineralogist in his determinative work—minerals like men may be known by the company they keep. In the ensuing detailed description of the minerals several such laws will be mentioned.

Summary.

The practical determination of minerals in the hand specimen consists in observing their crystal form, hardness, tenacity, cleavage if any, fracture, lustre, color and streak, specific gravity and association. Tables have been devised by mineralogists using these features as the means of distinguishing minerals one from another. With the aid of one of these the student is enabled after some practice to determine any of the well defined mineral species easily and accurately.

CHAPTER II.

GENERAL CHARACTERS OF ROCKS.

Difference between Minerals and Rocks.

A mineral is a homogeneous substance. A rock, however, is generally heterogeneous and usually consists of more than one mineral substance. A mineral occurs in nature generally imbedded in some other substance, or in a rock and not in an independent position, while a rock *is a geologically independent part of the earth's crust.* The minerals of which it is composed (mineral composition), their relation one to another (texture of the rock) and the mode of occurrence of the rock in the field must all be in harmony with the geological process by whose action the rock reached its present state. In order to know a rock thoroughly we must therefore know its mineral and chemical composition, its texture and its geological mode of occurrence.

Formation of Rocks.

Rocks result (1) from the cooling and solidification of a molten mass or magma (lava); (2) from the mechanical deposition or chemical precipitation of substances with or without the aid of organic life; (3) if rocks from either of the above classes be subjected to great pressure and heat, their texture and mineral composition is altered to such an extent that new rock types are produced.

Rock Texture.

The physical conditions under which a rock is formed leaves their impression on the finished product and find their expression primarily in the texture of the rock, that is, in the relation of the mineral components one to another. This imprint which the physical conditions at the period of formation leave on the rock may be compared to that of the die upon the coin. If gold or silver bullion be taken to the mint at Washington and stamped, it passes ever afterward as U. S. currency, by virtue of the stamp the die at the mint has left upon it.

Old Grecian and Roman coins which have been exposed to the action of the weather for centuries still exhibit traces of their original inscriptions. These we are able to decipher and thus learn something of the age to which they belong. We do not obtain our knowledge, however, from the metal of which the coin is made, as such, but from the impression which the metal bears, the stamp of the ancient Roman or Grecian die which gave the metal its outward shape.

The physical conditions under which a rock cools represents the die whose stamp is found inscribed in the relative arrangement and size of the mineral components embodied in the finished rock, that is, its texture. By means of the texture we are able not only to distinguish rocks formed under different conditions but also to state under what conditions they were formed.

Eruptive Rocks.

The molten rock mass or magma, which is forced up by a volcano like Vesuvius, or which wells up out of a large fissure or crack in the earth's crust as in Iceland, reaches the surface, flows over, cools rapidly and solidi-

fies, the outer crust first and then gradually the central portion. Such a product when solidified is known as an eruptive rock and represents the outcome of the cooling of a molten magma or lava originally situated beneath the earth's crust. The resulting rock must show indications of its rapid rate of cooling in the size and relative arrangement of the minerals which were formed during this process. Under such conditions they had but little time to assume crystalline shape and will therefore be small and irregular in outline. Part of the rock may even have cooled so quickly that minerals had no time at all to form and the magma simply solidified as glass. The minerals which had already formed before the eruption of the lava to the earth's surface will then be imbedded in a glassy background or groundmass as it is called.

If, however, the same molten magma had cooled very slowly and had taken years instead of days to solidify, the minerals then formed would have had ample time to assume definite crystal shape and to grow proportionally. The whole magma would have crystallized out and the resulting rock would have consisted of a mass of various crystallized minerals of fair size, grouped together according to certain laws. (Specimen No. 104).

Deep-Seated and Effusive Eruptive Rocks.

Such a state of slow cooling would evidently be realized were the rock magma to solidify deep down below the earth's surface where it is surrounded by other rocks which are poor conductors of heat. Rocks formed under these conditions are called *plutonic* or *deep-seated eruptive* rocks, to distinguish them from those formed by the cooling of similar molten magmas on the earth's surface and called *volcanic* or *effusive eruptive* rocks. (Specimen Nos. 57 and 61).

Sedimentary Rocks.

The rocks we have thus far considered were produced by the cooling and solidification of some molten rock magma. They may be formed, however, in other ways. If we observe rocks in the field we find them to be in a state of constant alteration. They crumble away, their chemical composition changes. The total effect of the action of the rain, the frost and the atmosphere on a rock is expressed by the term "weathering" and the products thus formed "the weathering products." During the Spring months all streams are swollen and turbid; they transport the fine grained detritus caused by the decay and disintegration of rocks exposed on the surface and deposit the same whenever the current stops. The ocean forms a great basin for deposit. The Mississippi alone carries yearly into the Gulf of Mexico enough sediment to cover one square mile under a layer 268 feet deep. The material, sand and mud, settles in layers and forms a bedded or stratified complex. This gradually consolidates by virtue of the pressure exerted by the overlying masses and the cementing action of percolating waters which deposit from solution solid substances, as limestone and silica. Rocks thus formed are known as *sedimentary* rocks and represent compact sediments deposited from former suspension in water.

Kinds of Sedimentary Rocks.

The material of which sedimentary rocks consist varies greatly. If it be simply grains of sand (quartz) the rock is termed sandstone (specimen No. 53). Solidified mud is known as shale (specimen No. 42). Great accumulations of shells and hard calcareous parts of former living organisms form on consolidation and cementation a familiar rock, limestone (specimen No. 49).

Difference between Sedimentary and Eruptive Rocks.

We have become acquainted with two great classes of rocks, eruptive and sedimentary, and are able to distinguish between them by their texture. Sedimentary rocks usually exhibit more or less distinct planes of deposition or stratification (specimen No. 83). Eruptive rocks show no such bedding planes (specimen No. 60). In eruptive rocks the mineral constituents are grouped according to the laws relative to the arrangement of mineral components precipitated out of a molten magma. In sedimentary rocks a totally different arrangement is found.

Metamorphic Rocks.

By subjecting any of the foregoing rocks, either eruptive or sedimentary, to great pressure it is possible to change not only their outward appearance but also their mineral composition.

Dynamic Metamorphism.

If a granite (specimen No. 105) undergo great pressure it alters to a banded rock called gneiss (specimen No. 89). By pressure shale passes into slate (specimen No. 87). The slate shingles of our roofs were originally soft beds of mud. Limestone under pressure passes into marble (specimen No. 86), sandstone into quartzite (specimen No. 88). This pressure is caused partly by the great weight of the overlying sediments and rocks but chiefly by the strains and internal movements and dislocations produced in the earth's crust by its gradual shrinking and contraction on cooling.

Contact Metamorphism.

Eruptive rocks frequently cause profound changes in the composition and texture of the surrounding rock masses into which they are intruded (contact metamorphism). In this way limestone is often changed to marble, brown coal to anthracite, etc.

Determination of Rocks.

In distinguishing rocks one from another in the hand specimens, we use primarily their mineral and chemical composition and their texture. We determine the minerals which constitute the rock as accurately as possible and observe their relative arrangement and abundance. The amounts may be obtained either by actual measurement or by making a chemical analysis of the rock and from it calculating the amount of each mineral present. The specific gravity of the rock should also be noted as it is frequently of great assistance in practical rock determination.

Geological Mode of Occurrence of Eruptive Rocks.

To know a rock thoroughly, however, we must also know how it occurs in nature. By observations in the field it has been found that deep-seated rocks appear usually as large masses intruded into the surrounding rocks either in the form of "intrusive sills or sheets," *i. e.*, intrusive sheets of eruptive rocks between sedimentary strata; or as "dikes," which are wall-like masses of rock, filling fissures in other rocks into which they have been forced; or as "bosses," dome-like masses which rise above the surrounding surface. Effusive or volcanic rocks occur, as their name indicates, in the form of lava flows or sheets spread over the earth's surface.

Sedimentary Rocks.

Sedimentary rocks if undisturbed are found in the position in which they were deposited resting on the rocks which formed the basin and shore line of the ocean at the time of their deposition. If, however, they have been tilted, or exposed to any of the natural forces of alteration they show traces of the fact in their present aspect and in their relation to the surrounding rock masses.

The Oldest Rocks in Michigan.

The oldest rocks visible in Michigan occur in the Upper Peninsula, where they form part of the so-called basement complex. They have been exposed so long to the action of weathering and forces of metamorphism that at times it is extremely difficult, if not impossible, to distinguish old altered sediments from old altered eruptive rocks. They all exhibit a more or less distinctly banded appearance or "schistose" structure (specimen No. 96) and belong to the class of metamorphic rocks. Any distinct remains of animal life which may have existed at the time of their formation have been obliterated and rendered unrecognizable. These old schists are cut by the granite and other massive rocks of the basement complex.

Typical rocks of the basement complex are shown by specimens Nos. 89 to 105 inclusive.

The Overlying Formations.

Directly above and resting on the basement complex the geologist encounters rocks of an entirely different character. Younger, less altered and undoubtedly of sedimentary origin, the relations they bear to the basement complex below indicate clearly that a long period of time intervened between the formation of the two—

that the rocks of the basement complex suffered deep erosion before the overlying sediments were deposited on them. This conclusion of the geologist is based on the similarity of the observed records to others that are now being inscribed in the earth's crust by geological agencies.

Unconformity.

The earth's surface is continually fluctuating, rising in certain districts, falling in others. If the changes in level take place rapidly earthquakes result and destruction and devastation may follow; if slowly we are unaware of them and can only perceive the differences by accurate observations and measurements. The work of the U. S. Coast and Geodetic Survey has proved that the position of our coast lines has changed slightly within the last century, receding in some localities, encroaching on the sea in others. In other countries, as Chili and Norway, these same phenomena have been observed. They show conclusively that slow oscillations are taking place. In a century the displacement may amount to only a few centimeters, but in the course of a geologic age, embracing thousands or millions of years, the movements assume enormous proportions. In this way great mountain ranges, as the Alps and the Rocky Mountains, have been formed; whole continents have been submerged for a time and have acted as basins for inpouring sediments. Sedimentary rocks are usually deposited on the ocean bottom. The submerged land, the basin, may be raised after a period of time and regain its former position as land. As such, however, it is subjected to the action of weathering and erosive agencies which gradually destroy the rock, cause it to crumble away and thus furnish products for other sedimentary rocks. The elevated land may again subside and sediments

be deposited anew on its eroded surface. From the relative position and different character of the two rocks thus formed, the one above the other, we are able to distinguish between them and to decide with certainty as to their history. A rock mass thus formed on the eroded surface of a second is said to rest unconformably on the latter. The unconformity indicates a time break, a period of upheaval and erosion, between the formation of the two.

The rocks of the basement complex were subjected to such a period of erosion before the overlying rocks were deposited. Hence an unconformity exists between the two groups. From the evidence thus far gathered it is probable that the time intervening between the formation of the basement complex and the deposition of the rocks immediately above was exceedingly long.

Huronian Era.

As a means of indicating this lapse of time geologists have placed a division line between the eras of formation of the two groups of rocks under discussion and have named the geological era in which the overlying rocks were deposited, the Huronian. The unconformity at the base of the Huronian rocks marks the lower limit of this era. The rocks below it belong to the basement complex, those directly above to the Huronian group.

Divisions of Huronian Era.

According to the latest researches of Professor Seaman, two further unconformities occur within the Huronian group, one at the base of an altered sandstone called the Ajibik quartzite and the second higher up in the scale at the base of the so-called Ishpeming formation. Accordingly the Huronian era has been divided into three

periods, the lower, middle and upper Huronian. Members of the middle Huronian rest unconformably on those of the lower Huronian; the upper Huronian system shows the same relations to the middle Huronian. Each one of these periods is again divided locally into several epochs, the description of which will be taken up later with that of the hand specimens.

Occurrence of Iron Ore Deposits.

All the great iron ore deposits of Upper Michigan are situated in the upper part of the middle Huronian and in the lower part of the upper Huronian.

The Huronian rocks are very old and are altered to a great extent but not to such a degree as those of the basement complex. Rocks show their age as well as human beings. The oldest rocks, like the visage of an old man, are wrinkled and checkered and bear the marks of the vicissitudes through which they have passed. To the geologist they unfold their own history and offer him impartial, truthful records of former events through which they have passed.

Typical rocks of the Huronian system may be studied in the hand specimens Nos. 63 to 88.

Subdivisions of Formations of Palaeozoic Era.

In the Upper Peninsula the rocks resting on the upper Huronian unconformably are called the Keweenaw series. It is the prevalent opinion of geologists that these Keweenaw rocks belong at the base of a third great group called the Palaeozoic and were formed in the earliest Palaeozoic times. The Palaeozoic era is divided into several periods for convenience. The lowest number is the Cambrian-Keweenaw series and the potsdam sandstone, after which the Silurian, Devonian, Carboniferous and Permian follow.

Keweenaw Age.

The Keweenaw age was a period of intense volcanic activity. Through great fissures and cracks in the earth's crust lava welled up and flowed over the ocean floor in the form of enormous sheets, one flow after another to the thickness of about 2,000 meters (6,000-7,000 feet). These lava sheets stretched out over an area extending from the eastern Canadian shore of Lake Superior on the east, to eastern Minnesota and northern Wisconsin on the west. They occur on the north shore of Lake Superior and on Isle Royale, and are well exposed on Keweenaw Point, from whence the epoch received its name.

As the Keweenaw lava flows were mostly submarine, extending as far as the coast, they are accompanied by interstratified beds of rocks formed of materials of erosion deposited between the individual lava flows.

Occurrence of Copper.

In these lava flows and in the interbedded rocks occurs the copper, which has made the mines of Michigan famous. It is found either in a native state or united with other elements in the form of some copper ore. At present only the native copper is mined.

Potsdam Sandstone.

After the eruptions of the Keweenaw epoch had ceased the deposition of the sedimentary materials still continued, forming the series known as the Potsdam. The Keweenaw lava flows are thus sometimes capped by the thick Potsdam sandstone formation (specimen No. 53). From this dark-red sandstone many of the finest

buildings in the Upper Peninsula and elsewhere have been constructed.

Examples of the copper bearing rocks are given in specimens Nos. 57 to 62, which are lavas; No. 56, which is conglomerate, and No. 55, which is shale.

Formation of Basin of N. W. end of Lake Superior.

At the end of the Keweenaw and Potsdam period extensive movements in the earth's crust took place in this region. The entire system of sediments and lava flows on the eastern edge was tilted up in such a way that the rock beds in Michigan instead of resting in a horizontal position, slope or dip at present to the north and northwest. Those in Minnesota and Isle Royale were tilted by a south to southeast acting force and consequently slope toward the south and southeast.

A plane passed through the earth's crust perpendicular to the surface and in the direction of the line A B on the map will be intersected by the above described rock groups in the way shown in diagram No. 1. From it we see that on the east the Keweenaw series of lava flows and Potsdam sandstone are tilted up and slope toward the west, while on the west they slope toward the east. The central portion of trough of the figure forms the basin of Lake Superior.

Formation of Palaeozoic Strata in Michigan.

A glance at the map issued by the Geological Survey of Michigan will make clear the chronological succession of the Michigan strata. The addenda at the left of the page place at the top of the list, the Archaean group,—taken to include the basement complex and the Huronian,—and at the bottom the youngest strata, the carboniferous, which occupy the central part of Michigan and is

marked coal. At the beginning of the Palaeozoic era, Michigan was a wide submerged basin, forming a bay or arm of a large Palaeozoic sea. Into this basin the sediments of the inpouring streams were deposited, gradually filling it up and making it more and more shallow.

Distribution of Silurian Strata.

The original coast line of the lower Silurian strata (indicated on the map by the red color patterns) starts in Canada at northeast corner of the map and runs through the Upper Peninsula down along the coast of Wisconsin.

Devonian Strata.

Those of the overlying age, the Devonian strata (purple patterns) follow the trend of Lake Michigan and Lake Huron and have been largely eaten away and submerged under the two lakes.

Carboniferous Strata.

The Carboniferous strata (blue patterns) occupy the central part of the Lower Peninsula.

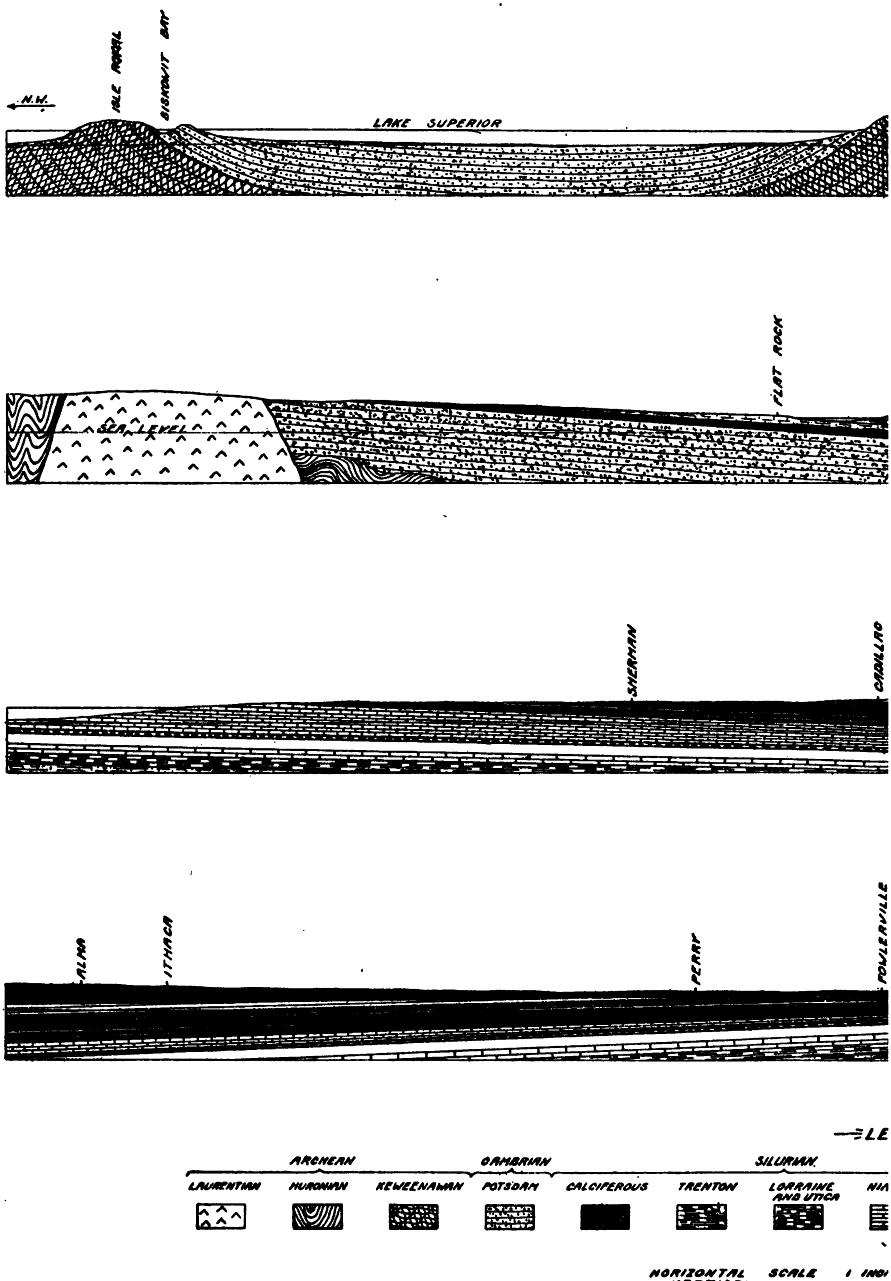
As we depart from the coal basin the strata becomes gradually older. For example, in going from the northern edge of the coal basin to the Straits of Mackinaw, one passes successively from younger to older rocks. The geological structure of the Lower Peninsula has been compared to a pile of plates of various dimensions, arranged according to size, the smallest at the top. If we were to take a shallow basin or plate of the same general outline as that of the outer edge of the red colored patterns (Silurian) and place within the same, layers of different colored clay (thinner toward the

center) one above the other, each succeeding layer to have the same general outline as that of the colored patterns, the finished product would give a good idea of the geological structure of the state (see cross section). The carboniferous strata are practically surrounded on all sides by Devonian rocks and form the central residual basin of the sea which once covered Michigan but which in the course of time became filled with sediments and gradually dried out. The numerous beds of salt and gypsum found in the rocks of various ages in Michigan indicate that a process of evaporation, drying out, caused this Michigan arm of the ancient Palaeozoic sea to become smaller. It is noteworthy, that the most central part, the last remnant of the shallow bay constitutes the coal basin. The sea had become so shallow that vegetation was able to force its way gradually farther out into the sea until a great swamp or jungle resulted. Under such conditions trees and plants grow luxuriantly. All fallen material is protected from decay by the underlying water, and therefore gradually accumulates, the water rising accordingly. In the course of time peat is formed, which in turn alters to soft bituminous coal. The present product of the Michigan coal beds is a soft and brown coal. If great pressure and heat be applied to this soft coal, anthracite results. All anthracite was originally soft coal.

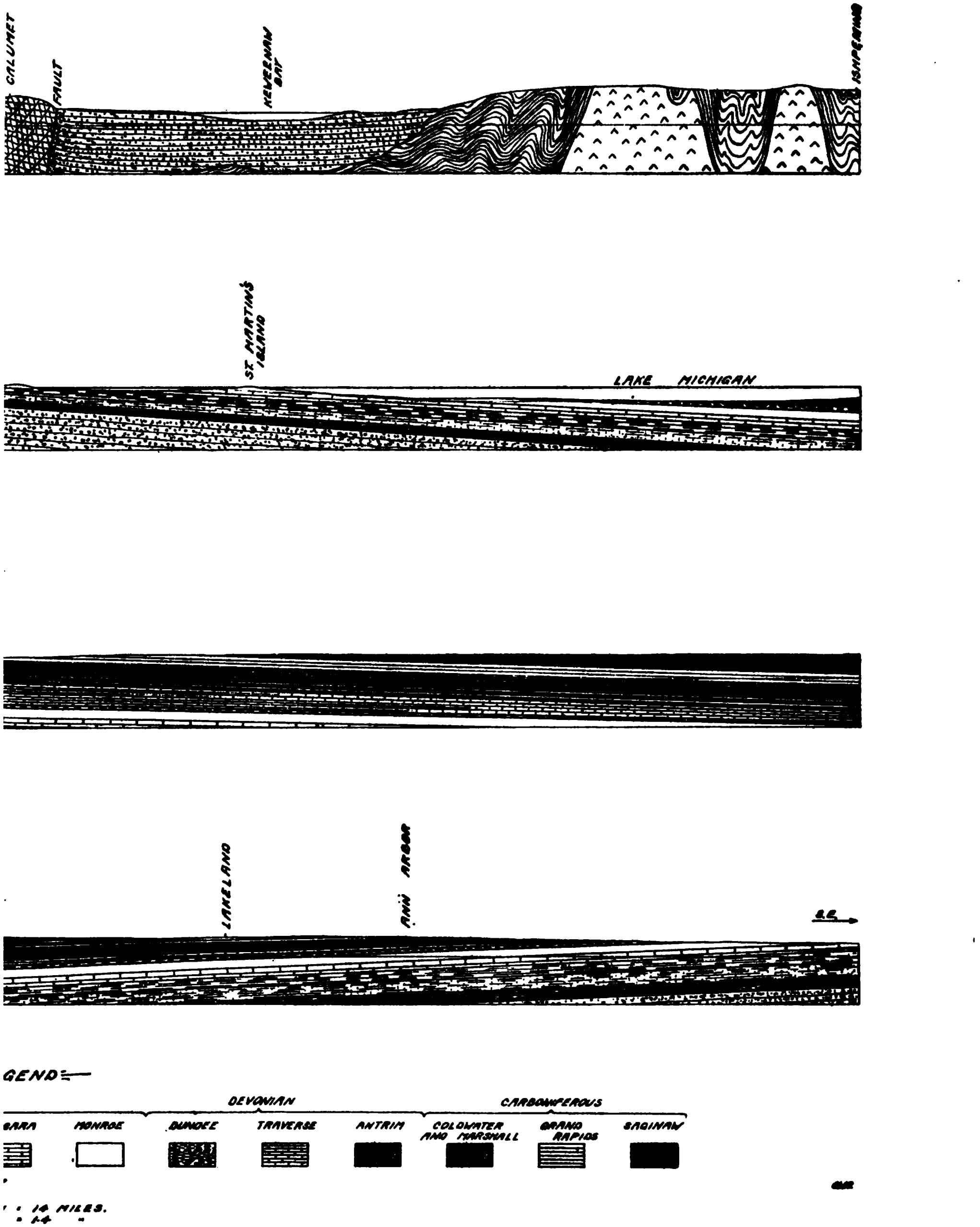
The character of the rocks of these ages may be studied in the specimens Nos. 39-52.

Glacial Period.

From the time of the disappearance of the Carboniferous sea down to the present, Michigan has not been again submerged. In recent geological times, however, the state was covered at several different intervals by enormous sheets of ice as Greenland is at the present day. Traces of the action of this continental glacier may be



GEOLOGICAL CROSS SECTION OF MICHIGA



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seen in many different parts of the state. Glaciers in the form of vast moving sheets of ice carry a large amount of debris on their surface, and also pick up large quantities of the underlying rocks and rock fragments and transport them for long distances. At the end of the glacier the ice gradually melts and deposits in the form of mounds and hills the material which it has carried and pushed along. These elevations are called moraines. In some parts of Michigan these beds of material deposited by the glaciers are 70 to 100 meters (200-300 feet) thick. As a result of the mode of transportation by ice, the larger rounded and scratched boulders are intermingled with the finer pebbles and sand, the whole being a heterogeneous mass of boulders, pebbles and sand, mixed together with no indication of separation such as we find in deposits produced by the deposition of materials out of water.

Importance of Glacial Period for Michigan.

The larger part of the material forming the glacial drifts came originally from Canada and consists of boulders of granite, gneiss, etc., from the great northern Archaean area. Rocks of this type contain a large amount of alkalies and phosphates, both highly important ingredients from an agricultural standpoint as fertilizers.

The low rolling hills of the Lower Peninsula are mostly old glacial moraines on the sides of which thrive Michigan's excellent fruits. We have seen above that the greater part of the material constituting these same hills was originally carried down from Canada. Nature has assisted us as a state in a marked degree. The Upper Peninsula is favored with its enormous deposits of iron ore and copper and its vast forests, while the Lower Peninsula can boast of its salt wells and gypsum beds, its coal mines and its good farming lands.

Purpose of Collection.

In this brief summary of the geology of Michigan many important points have been purposely left out. The object in view coincides with that of the collection itself, which is intended to give merely a general idea of the common minerals and rocks of Michigan. Rare specimens have been avoided. A student interested in this branch of nature study can go out in the field and readily gather for himself many of the specimens represented in the collection.

CHAPTER III.

SPECIFIC DESCRIPTIONS OF MINERALS.

In the following description of minerals no mineralogical classification has been attempted. The iron ores and the minerals which occur with them, are considered first. After which follow in the order named the copper ores and their associated minerals, the rock forming minerals, and, lastly, the minerals of southern Michigan. To economize space there is first given a concise description of the characteristic features of the mineral, next, special traits of the individual specimen, lastly, such facts of interest as appertain to its economic value.

THE IRON ORES AND ASSOCIATED MINERALS.

Iron ore in Michigan dates back to 1844. A party of government engineers and surveyors, sent out by Douglass Houghton, the first State Geologist of Michigan, under the immediate charge of Mr. Burt, the inventor of

the solar compass, noticed a marked local attraction of their compass needle at a point near the present city of Negaunee. As a result of their report to the government many explorers and mining engineers became interested in the district and began mining the ore at several different localities. The villages of Ishpeming and Negaunee were founded and grew up with the mines. Twenty-five years later over seventy different mining companies had been formed for the purpose of developing the mines. The production of iron ore increased to such an extent that Michigan soon outdistanced all other states, having an output of 1,948,334 tons in 1880, 7,185,139 tons in 1890, and 9,079,827 tons in 1900. The annual production of all the Lake Superior ranges in 1900 was 28,524,648 long tons.

The most important iron ores mined in Michigan are hematite, limonite, magnetite and martite. With them two manganese ores of commercial value, manganite and pyrolusite, occur at several of the mines. There are also a number of minerals of minor economic significance, as pyrite, calcite, barite, apatite, grunerite, garnet, masonite, tourmaline, molybdenite and many others.

HEMATITE (KIDNEY ORE).

Specimen No. 1 from Salisbury Mine, Ishpeming.

Color, dark steel gray or iron black; when earthy, red. Streak, cherry-red or reddish brown. Lustre, metallic to sub-metallic. Fracture, uneven. Brittle. Hardness, 5-6. Specific gravity, 5.2. Chemical composition, Fe_2O_3. Oxygen 30%, iron 70%.

This mineral was known to the ancient Greeks and Romans, who gave it the name hematite, signifying blood stone from its blood-red streak (color in a powdered condition). As a result of the red streak the iron

mining towns of the Upper Pensinsula such as Ishpeming, Negaunee, Ironwood, Ironmountain, etc., are known by their reddish hue. The streets and houses and in a short time the shoes, clothes, etc., become coated and filled with this red dust of hematite, which is extremely difficult to remove. The ore from the mines contains from 60% to 68% metallic iron and is found in many different conditions, as soft hematite, hard ore, specular ore, kidney ore (specimen No. 73) named after its reniform surface. It is the chief ore of the iron districts. The reddle used by jewellers is a fine argillaceous variety of hematite.

LIMONITE.

Specimen No. 2 from N. Champion.

Color, various shades of brown; when earthy, yellow, ochre yellow. Streak, yellowish brown. Brittle. Hardness, 5-6 if compact. Specific gravity, 3.6 to 4.0. Chemical composition $2Fe_2O_3,3H_2O$. Oxygen 35.7%, iron 59.8%, water 4.5%.

Chemically limonite is hematite plus water ($2Fe_2O_3$, $3H_2O$). Hematite often alters to limonite, changing its streak thereby from red to yellow. It is not so rich an ore as hematite but is mined on a large scale together with the latter. Limonite is the coloring base of the yellow and brown ochers used in the arts. It frequently occurs in swamp deposits and is then known as bog iron ore.

MAGNETITE.

Specimen No. 3 from Champion Mine, Champion.

Color, iron black. Streak, black. Lustre, metallic splendent to sub-metallic and dull. Fracture, uneven. Brittle. Hardness, 5.5. Specific gravity, 5.17. Chemical composition, Fe_3O_4. Oxygen, 27.6%; iron, 72.4%.

In magnetite a parting resembling cleavage is often noticeable parallel to the crystal faces.

This mineral is magnetic and deflects the needle of a compass. Its powder clings to the arms of a bar or horseshoe magnet. This specimen No. 3 consists of innumerable small crystals cemented together, giving the whole a granular appearance. Its presence in the ores near Negaunee led to their early discovery and subsequent development. According to Pliny, the old Roman scientist and writer, its first discovery was also due to the same trait. A shepherd boy named Magnes is said to have noticed that part of the rock on Mt. Ida in N. W. Asia Minor clung to the nails in his boots and rendered walking difficult.

Blocks of magnetite loadstone were used by Dutch mariners as compass needles long before the latter had been invented. Magnetite is smelted chiefly for soft iron.

MARTITE.

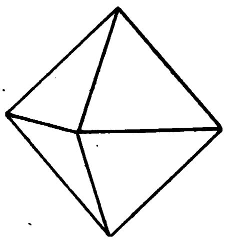

FIG. 1—Martite.

Specimen No. 4 from Cleveland Mine, Ishpeming.

Color, iron black with a bronzed tarnish; crystal faces, steel gray in reflected light. Streak, reddish to purplish brown. Lustre, sub-metallic. Fracture, conchoidal. Brittle. Hardness, 6-7. Specific gravity, 4.6 to 5.2. Not magnetic or only feebly so. Chemical composition Fe_2O_3, same as hematite.

The small perfect crystals of martite in the specimen are imbedded in a soft greenish substance called chlorite. Both chlorite and martite are alteration products of other minerals. They are a direct result of the chemical processes which were instrumental in the formation of the ore bodies. It has the chemical composition of hematite

but differs from the latter in its outer crystal form. Martite assumes the crystal form of magnetite, the mineral which it replaces, and as such is known as a pseudomorph, *i. e.,* of a false, deceiving shape. Martite is rare and not mined to any extent.

MANGANITE.

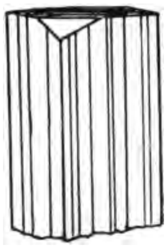

FIG. 2—Manganite.

Specimen No. 5 from Lucy Mine, Negaunee.

Color, dark steel gray to iron black. Streak, reddish brown, often nearly black. Lustre, sub-metallic. Brittle. Fracture, uneven. Cleavage, perfect and easily recognizable. Crystals, long and prismatic in shape. Hardness, 4. Specific gravity, 4.3. Chemical composition, $Mn_2O_3H_2O$. Oxygen, 37.3%; manganese, 62.4%; water, 10.3%.

The origin of the manganite is the same as that of the iron ores. In several of the iron ore mines large quantities of manganite are found in connection with the iron ore, the two having been deposited together. Manganite is the hydrated form of manganese oxide and crystallizes in long, flattened prisms, which are deeply striated vertically. The rounded terminal faces of the crystals of specimen No. 5 are characteristic. Manganese ores are valuable for making alloys, and are used as oxidizers and as coloring agents. Manganese alloyed with iron furnishes chilled iron castings which are tougher, stronger and more durable than those of pig iron alone and serve well for car wheels, etc. The pig iron from the Lake Superior region owes its excellent quality in a large measure to a small percentage of manganese. In glass manufacture manganese ores are used both as discoloring and coloring agents.

PYROLUSITE.

Specimen No. 6, Newport Mine, Ironwood.

Color, iron black to dark steel gray. Streak, black. Lustre, metallic to sub-metallic. Soft, writes black. Hardness, 2-2.5. Specific gravity, 4.82. Chemical composition, MnO_2. Oxygen, 36.9%; manganese, 63.1%.

Pyrolusite is soft and soils the fingers on handling, while manganite is hard and does not rub off. The fibrous texture of the crystals of the specimen should be noted. Pyrolusite derives its name from two Greek words signifying to wash in fire, because of its property of rendering glass containing iron colorless and transparent. Many heavy glass tumblers in time become noticeably pink. The manganese used originally to counteract the effect of the coloring iron is gradually set free and becomes itself a coloring agent. It is also used as an oxidizing agent in the manufacture of bromine and chlorine.

PYRITE.

Specimen No. 7 from Champion Mine, Champion.

Color, uniform pale brass yellow. Streak, greenish black or brownish black. Lustre, metallic; splendent to glistening. Fracture, uneven. Brittle. Hardness, 6-6.5. Specific gravity, 5.00. Chemical composition, FeS_2. Sulphur, 53%; iron, 46.6%.

Pyrite is formed by the action of sulphuretted gases and solutions on iron compounds. The usual form of pyrite crystals is that of a cube, the faces of which frequently exhibit fine striations (specimen No. 7). Pyrite as an economic mineral contains two important ingredients, iron and sulphur. The sulphur is used chiefly for the manufacture of sulphuric acid. As an ore pyrite does not occur in large enough quantities in Michigan to be mined, but as a mineral it is found widely distributed in rocks of all ages.

CALCITE.

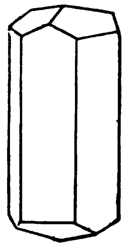

FIG. 3—Calcite.

Specimen No. 8 from Negaunee Mine,
Color, white to colorless, also pale
and Columbia Mine, Negaunee.
shades of gray, yellow, red, green, blue, etc. Streak, whitish or grayish. Transparent to opaque. Lustre, vitreous to sub-vitreous. Cleavage, highly perfect in three similar directions. Fracture, conchoidal. Hardness, 3. Specific gravity, 2.71. Chemical composition, $CaCO_3$. Carbon dioxide, 44.0%; lime, 56.0%. Calcite occurs in a variety of crystal forms and crystalline aggregates.

Calcite as a crystallized mineral shows perfect cleavage. Specimen No. 25 is but a cleavage fragment of a larger crystal. Calcite is formed in the iron districts by precipitation from solution in percolating waters. These waters contain much carbonic acid gas, which attacks lime-bearing minerals and thus forms carbonate of lime or calcite. The calcite crystals of specimen No. 8 rest in a cavity in the iron ore from the Negaunee Mine, Negaunee. The crystals showing flat terminations—nail-head spar—are from the Cambria Mine. Those with sharper terminations (dog-tooth spar) are from the Negaunee Mine. Pure calcite if transparent and clear like glass is extremely valuable when found in large crystals. The only large deposit of such calcite known at present is in Iceland. It is owned and controlled by the Danish government. This one quarry, 72 feet long and 36 feet wide, has supplied and still supplies all the calcite used in the manufacture of Nicol prisms for microscopes and devices for the production of polarized light. The quarry at present is worked but little—the best material having been extracted. Manufacturers of optical instruments have

great difficulty in obtaining suitable prisms and in the near future either a new calcite quarry must be discovered or a new method devised for obtaining polarized light.

Calcite usually contains foreign discoloring substances which render it unfit for optical instruments. When moistened with dilute acid it effervesces, giving forth carbonic acid gas which is used in the manufacture of appolinaris and other carbonated waters. If calcite be heated to a high temperature the carbonic acid gas passes off leaving calcium oxide or unslacked lime, a product important to the mason and plasterer. Owing to its many good qualities calcite has been studied more than any other mineral. It has even been said that a complete history of the study of calcite would be a good history of the science of mineralogy.

BARITE.

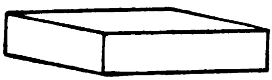

FIG. 4—Barite.

Specimen No. 9, Lucy Mine, Negaunee.

Color, white, also pale yellow, red, blue and brown. Streak, white. Transparent to opaque. Lustre, vitreous; slightly resinous. Brittle. Fracture, uneven. Cleavage, perfect along three different planes. Hardness, 3. Specific gravity, 4.5. Chemical composition, $BaSO_4$. Sulphur trioxide, 34.3%; barium oxide, 65.7%. Crystals, tabular; occasionally prismatic.

As its name indicates, barite is extremely heavy. It does not effervesce with dilute acid as dces calcite. It occurs in the form of flat plates and cleaves parallel to one face perfectly and to two others well. The angles which these faces make one with another are not equal as they are in calcite. A mass in which a number of imperfect crystals of a mineral are

intergrown is said to be crystalline. The material on which the tabular crystals of the specimen No. 9 rest, consists also of barite but intergrown to form a crystalline aggregate. Barite is one of the heaviest of the colorless non-metallic minerals. It is mined chiefly for the element barium. At a high temperature barium is volatile and colors the flame green, a property made use of in fireworks to produce green color effects. Barite serves as an adulterant for white lead, also to give weight and body to certain kinds of paper.

APATITE ON LIMONITE.

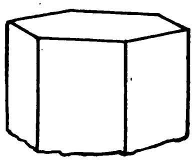

FIG. 5—Apatite.

Specimen No. 10, North Champion.

Color, variable; transparent to opaque. Lustre, vitreous, inclining to sub-resinous. Fracture, conchoidal and even. Cleavage, imperfect. Brittle. Hardness, 4.5-5. Specific gravity, 3.2. Crystals, prismatic, hexagonal in outline. Chemical composition, $3Ca_3P_2O_8+Ca(F,Cl)_2$.

The minute, grayish, yellow to reddish, hexagonal prisms scattered over the surface of the brown iron ore of this specimen illustrate the mode of occurrence of apatite crystals in the iron ores. Larger, better developed crystals are extremely rare. Whether all the phosphorous contained in the iron ores is combined as apatite or not is a problem yet unsolved. The larger white crystals on some of the specimens No. 10 are of another mineral called dolomite. Apatite contains a large percentage of phosphorous, an element indispensable to all life, both animal and vegetable, but unfavorable to the smelting of

iron ores. An iron ore high in phosphorous brings a much lower price than one low in the same. Apatite is found in numerous rocks in crystals. In certain places where it is unusually plentiful (as in Norway and Canada) it is mined or quarried for fertilizing purposes.

GRUNERITE.

Specimen No. 11, Michigamme Mine, Michigamme.

Color, gray to brown. Streak, white. Lustre, silky. Cleavage, perfect along two prism planes, making an angle of about 124 degrees one with the other. Hardness, 6. Specific gravity, 3.71. Crystals, asbestiform or lamellar fibrous. Chemical composition, $FeSiO_3$. Silicon dioxide, about 44% ; ferrous dioxide, 52% ; other elements, 4%.

Grunerite is a compound of iron and silica and crystallizes in fine needles and prisms, which often radiate out in all directions, forming rounded balls or spherical aggregates, well shown in the specimen.

Grunerite is formed usually under the action of pressure and heat and hence occurs in rock masses which have been subjected to great pressure, that is, in metamorphic rocks such as those of the basement complex and the Huronian group. The mineral in which the grunerite needles are imbedded is magnetite. The rock is known as a magnetic grunerite schist and is a metamorphic product of the original cherty iron carbonate, the rock from which most of the Michigan ore bodies have been derived. (See page 91.) Although grunerite contains 52.2% of iron it is of little or no economic value because of the expense necessary to separate the iron from the silica.

GARNET.

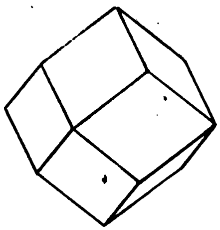

FIG. 6—Garnet.

Specimen No. 12, Michigamme Mine, Michigamme.

Color, red, brown, yellow, white, apple green. Streak, white. Lustre, vitreous to resinous. Transparent to sub-translucent. Fracture, uneven. Brittle. Cleavdge, indistinct. Hardness, 6.57.5. Specific gravity, 3.1-4.3. Chemical composition, a complex silicate of calcium, magnesium, iron, manganese, albuminum and other elements.

The mode of formation of garnet is similar to that of grunerite—the crystalform of garnet is one of its most characteristic features. In its natural state it usually occurs in the form of Fig. 7 (specimen No. 88). The color of garnets varies with their chemical composition. Garnet sometimes affords beautiful gems. The variety used as such is of a deep red color. Michigan garnets are of this color but not clear and fresh enough for commercial purposes. The specimen is more or less altered to the soft green mineral mentioned above as occurring with martite and called chlorite. Garnet has a high specific gravity.

MASONITE.

Specimen No. 13 from Champion Mine, Champion.

Color, dark gray, greenish gray to greenish black. Streak, uncolored or grayish. Lustre of surface of cleavage, somewhat pearly. Laminæ, brittle. Cleavage, perfect in one direction. Hardness, 6.5. Specific gravity, 3.54. Chemical composition, $H_2(FeM_g)Al_2SiO_7$.

The large, rounded, undulating, mottled cleavage faces of specimen No. 13 are peculiar to masonite. Masonite

is found only in rocks which have suffered intense metamorphism, and in Michigan is thus confined to the iron ranges and underlying rocks. It contains some iron but at present has no practical value.

TOURMALINE.

Specimen No. 14 from Champion Mine, Champion.

Color, most commonly black, brownish or bluish black; many other shades of color are also found. Streak, uncolored. Lustre, vitreous to resinous. Brittle. Fracture, uneven. Cleavage, very imperfect. Hardness, 7-7.5. Specific gravity, 3.0-3.2. Chemical composition, a complex silicate of many elements, chiefly a borosilicate of aluminum.

Characterized in the present specimen by its long, slender, striated prisms which cut through the white mineral, quartz, which encloses them. In specimen No. 90 some pyrite occurs disseminated through the rock, also in some specimens more or less amphibole. In the study of light, tourmaline has played an important part, owing to the fact that it absorbs a greater part of the light passing through its crystals along certain directions. Certain varieties of tourmaline are used for ornamental purposes.

MOLYBDENITE.

Specimen No. 15 from Michigan Gold Mine, near Ishpeming.

Color, pure lead gray; a bluish gray trace on paper; on glazed porcelain, slightly greenish. Luster, metallic. Feels greasy. Laminæ, very flexible, not elastic. Sectile. Cleavage, along one plane very perfect. Hardness, 1 to 1.5. Specific gravity, 4.7. Crystals, tabular, hexa-

gonal in form. Chemical composition, MoS_2. Sulphur, 40% ; molybdenum, 60%.

Molybdenite was named from its resemblance to lead compounds. It was formerly mistaken for these and also for graphite, from which, however, it may be readily distinguished by its platy structure and its greenish streak on glazed porcelain. In the specimen it is mixed with quartz and enclosed in a schistose finely crystalline, greenish rock from the basement complex group. It usually occurs scattered in small flakes in many kinds of rocks. It is used chiefly for rendering chrome steel self-hardening, also to give a bright blue color to porcelain, and in determining the phosphorous in iron ores.

COPPER AND ASSOCIATED MINERALS.

Copper was first discovered in Michigan by the Indians, who found it in loose blocks and water worn boulders along the shore on Keweenaw Point. They regarded masses of native copper with superstitious awe and worshipped them, considering them a present from the gods inhabiting the waters. They preserved the copper blocks wrapped up with their most precious articles, handing them down as heirlooms and cherishing them as household gods. In the course of time the copper found its way to the Indian tribes throughout the northwest. In the seventeenth century when the French Jesuit missionaries visited the Lake Superior district they heard of the copper regions, saw the copper from them, but were unable to find them as the Indians would not reveal their exact location. Hence no large mining enterprises resulted from the work of these earnest pioneers. Not until the nineteenth century, about 1840 and later, when the government engineers and geologists made a survey and report of the region did the copper district

attract the notice of mining men and explorers. Since that time the production of copper has increased so that at present about 200,000,000, pounds are mined annually.

COPPER.

Specimen No. 16 from Quincy Mine, Hancock.

Color, copper-red. Streak, metallic shining. Lustre, metallic. Fracture, hackly. Opaque. Highly ductile and malleable. Hardness, 2.5 to 3. Specific gravity, 8.84. Chemical composition, pure copper, often containing some silver, arsenic and other elements.

The uses and properties of copper are too well known to require description here. Copper was used by the ancients and was obtained by them in the Island of Cyprus, whence the name cuprum or copper. They fashioned it into vessels of various shapes, into ornaments and used it in the manufacture of bronze, a mixture of tin and copper.

In Michigan the copper occurs in a native state in certain ancient lavas, called metaphyres or basalt, and their interbedded conglomerates. The copper bearing formation of the Keweenaw series extends in our state from the N. E. end of Keweenaw Point in a S. W. direction parallel to the coast into Wisconsin (compare map).

CUPRITE.

Specimen No. 17 from Allouez Mine, near Calumet.

Color, red of various shades. Streak, shining brownish red. Lustre, adamantine or sub-metallic. Fracture, uneven. Cleavage, interrupted, indistinct. Hardness, 3.5 to 4. Specific gravity, 6.0. Sub-transparent. Chemical composition, Cu_2O. Oxygen, 11.2%; copper, 88.8%.

The action of the atmospheric agencies, such as oxygen, carbon dioxide and water, on the native copper fre-

quently produces changes, resulting in the formation of new minerals among which cuprite, malachite and chrysocolla are the most common. Cuprite is purely an oxidation product of copper. It is brittle, has sub-metallic lustre and is sub-transparent. The red rock in which it is interbedded is a conglomerate. The fibrous, apple-green mineral on some specimens of Nos. 78 and 98 is malachite. The dense, greenish blue mineral is chrysocolla. It is valuable only for the copper it contains.

CHRYSOCOLLA.

Specimen No. 18 from Allouez Mine, near Calumet.

Color, various shades of green and blue. Lustre, vitreous, shining. Streak, white. Translucent to opaque. Brittle. Fracture, conchoidal. Hardness, 3 to 4. Specific gravity, 2.2. Chemical composition, $CuSiO_3+2H_2O$. Copper oxide, 45.2%.

Chrysocolla signifies in Greek glue for gold and was the name of a material used in soldering gold. Its color varies from bluish green to turquois blue and sky blue. Crystals of chrysocolla have not been observed. In Michigan it does not occur in sufficient quantities to be mined advantageously. The original copper which was deposited between the pebbles of the conglomerate, has in this case united with the silica (cementing material of the pebbles) and water and formed chrysocolla.

DOMEYKITE.

Specimen No. 19 from Mohawk Mine, near Calumet.

Color, tin white to steel gray with a yellow to brown iridescent tarnish. Lustre, metallic but dull on exposure. Fracture, uneven. Hardness, 3 to 3.5. Specific gravity, 7.2 to 7.7. Chemical composition, Cu_3As. Copper, 71.7%.

Domeykite is not found in nature in crystals but always as a finely, crystalline, brassy looking, brittle aggregate. It is found in veins and pockets in the Keweenaw melaphyres. The white cleavable mineral found with the domeykite is calcite.

Domeykite is not an important copper ore. The copper it contains is extracted by smelting process. It occurs in connection with the native copper in the Keweenaw series of rocks. In comparison with the native copper the amount is small, though it is occasionally mined.

CHALCOCITE.

Specimen No. 20 from Champion Mine, near Houghton, and No. 21 from Mt. Mesnard, near Marquette.

Color and streak, black, lead gray, dull. Lustre, metallic. Brittle. Fracture, conchoidal. Cleavage, indistinct. Opaque. Hardness, 2.5 to 3. Specific gravity, 5.7. Chemical composition, Cu_2S. Copper, 79.8%.

Copper sulphide (Cu_2S), soft and with lead gray streak. Specimen No. 20 was taken from the copper veins of the Champion Mine, near Houghton, where it is imbedded in the quartz vein material. Specimen No. 21 was collected on Mt. Mesnard, a large bluff south of Marquette. It occurs associated with slate which it intersects in a network of veins. The veins are small and not important. Chalcocite is an important ore of copper.

CHALCOPYRITE.

Specimen No. 22 from the Baltic Mine, near Houghton.

Color, brass yellow, often tarnished and iridescent. Streak, greenish black. Lustre, metallic. Opaque. Fracture, uneven. Cleavage, not always distinct. Brit-

tle. Hardness, 3.5 to 4. Specific gravity, 4.1 to 4.3. Chemical composition, $CuFeS_2$. Copper, 34.5%; iron, 30.5%.

Chalcopyrite, or copper pyrites, was known to the ancients and is mentioned by Aristotle in his writings. The mineral with which it is associated in specimen No. 22 is calcite, a mineral which frequently accompanies metalliferous deposits. Chalcopyrite, although not important as an ore in Michigan, is the principal ore of the Cornwall mines in England, and carries the copper of the Rio Tinto mines in Spain.

BORNITE.

Specimen No. 23 from the Baltic Mine, near Houghton.

Color, copper red to pinchbeck brown on fresh fracture, iridescent on tarnish. Streak, light grayish black. Opaque. Luster, metallic. Fracture, uneven. Brittle. Hardness, 3. Specific gravity, 4.9 to 5.4. Chemical composition, Cu_3FeS_3. Copper, 55.5%; iron, 16.4%.

Bornite is called by the miners peacock ore and purple copper ore, owing to the iridescent, peacock like colors the mineral assumes in tarnishing. On a fresh farcture surface the color of bornite lies between a copper red and a pinchbeck brown, which, however, soon gives way to the more brilliant tarnish hues seen in the specimen. This mineral is a valuable copper ore, where abundant, but is not mined in Michigan.

Of the products of alteration and minerals deposited out of solution found associated with the copper ores, the following are among the most important: Epidote, calcite, prehnite, analcite, datolite and apophyllite. None of these have any economic value except for ornamental purposes.

EPIDOTE.

Specimen No. 24 from Centennial, Calumet.

Color, various shades of green and yellow. Lustre, vitreous. Streak, uncolored. Transparent to opaque. Fracture, uneven. Cleavage, perfect along one plane and imperfect along another. Brittle. Hardness, 6 to 7. Specific gravity, 3.2 to 3.5. Chemical composition, $HCa_2(Al,Fe)_3Si_3O_{13}$. Epidote is a complex hydrous silicate of calcium, aluminum and more or less iron.

This specimen shows the green crystalline epidote in the copper-bearing melaphyre. The original minerals constituting the melaphyre have been altered by the action of the weathering agencies and epidote thus produced, together with other secondary mineral, as chlorite, serpentine, etc. It is found only in small patches scattered through the decomposed melaphyre, either filling up narrow cracks and seams or disseminated through the entire mass.

CALCITE.

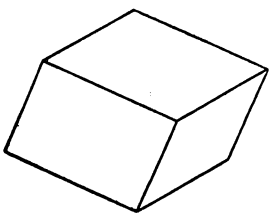

FIG. 7—Calcite.

Specimen No. 25 from Copper Falls Mine, Copper Falls.

The properties of this specimen are identical with those of specimen No. 8, described above. The specimen was collected from a large fissure vein in which the calcite was precipitated by percolating waters and is but a cleavage fragment of a much larger crystal. Unfortunately this material is not pure and transparent enough to be used for optical purposes.

PREHNITE.

Specimen No. 26 from Phoenix Mine, Phoenix.

Color, light shades of green. Sub-transparent to translucent. Streak, uncolored. Lustre, vitreous. Brittle. Fracture, uneven. Cleavage, distinct along one plane. Hardness, 6 to 6.5. Specific gravity, 2.8 to 2.95. Chemical composition, $H_2Ca_2Al_2Si_8O_{12}$. A complex hydrous silicate of calcium and aluminum.

Prehnite occurs in the Lake Superior region associated with copper, datolite, etc., and is found usually in the form of radial, barrel-shaped to reniform aggregates of a light apple to oil green color. One cleavage is noticeable.

ANALCITE.

White specimen No. 27, near Calumet, and red one from Copper Harbor.

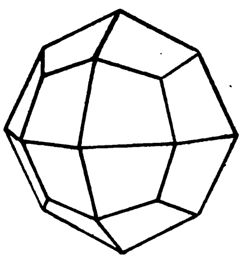

Fig. 8—Analcite.

Colorless, white, grayish and reddish white. Streak, uncolored. Lustre, vitreous. Brittle. Fracture, sub-conchoidal. Hardness, 5 to 5.5. Specific gravity, 2.27. Chemical composition, $NaFeS{:}_2O_6 + H_2O$. A hydrous silicate of aluminum and sodium.

The most typical feature of analcite is its crystalform and glassy appearance. The shape of the non-distorted crystals is that of Fig. 10. The small faces are four sided and of vitreous lustre. Two variations are represented in this collection, one colorless to milky from the Old Colony Mine, near Calumet, and the second, from Copper Harbor, dark red from enclosed copper oxide. The crystals usually occur in cavities in the melaphyre, often geode-like in aspect.

DATOLITE.

Specimen No. 28 from Copper Falls Mines, Copper Falls.

Color, white, grayish, pinkish, pale green and other shades. Streak, white. Transparent to translucent, opaque white. Lustre, vitreous. Brittle. Fracture, uneven. Hardness, 5 to 5.5. Specific gravity, 2.9 to 3.0. Chemical composition, Ca(BOH)S:O_4. A hydrous silicate of calcium and boron.

A silicate of calcium containing boron hydroxide. Crystals of datolite, such as specimen No. 28, are found only in a few places in Michigan. Its usual form in this state is that of specimen No. 29, compact and massive. This type of datolite is highly prized by mineral collectors, owing to the great variety of colors it presents on polishing. Many of the mineral cabinets of the old mining captains of the Copper Country are filled with polished specimens of this mineral. To add to its beauty particles of native copper are frequently enclosed within the datolite and sparkle when the specimen is examined and turned to the light.

APOPHYLLITE.

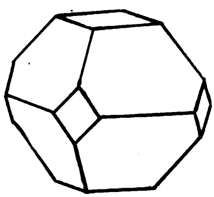

FIG. 9—Apophyllite.

Specimen No. 30 from the Phoenix Mine, Phoenix.

Color, white or grayish. Transparent. Streak, colorless. Lustre, vitreous, on cleavage plane pearly. Brittle. Fracture, uneven. Cleavage, highly perfect along one plane. Hardness, 4.5 to 5. Specific gravity, 2.3 to 2.4. Chemical composition, K_2O, $CaO_{16}SiO_{16}H_2O$. A complex hydrous silicate of potassium and calcium with some flourine.

The typical crystalform of apophyllite is that of Fig. 9. The crystals usually lie scattered over a background of calcite and other minerals formed in the same vein. The rock in which the vein occurs is the copper-bearing melaphyre.

ROCK FORMING MINERALS OF NORTHERN MICHIGAN.

The mineralogical composition of most rocks is extremely simple. They consist chiefly of minerals called silicates which contain silicic acid combined in variable proportions with other elements. The most important rock forming silicates are quartz, feldspar, mica, amphibole, pyroxene and olivene. They are found in many of the rocks of this collection. Without a good knowledge of these few silicates the description of a rock cannot be studied to advantage. To know a rock thoroughly its mineral composition must be clearly understood.

QUARTZ.

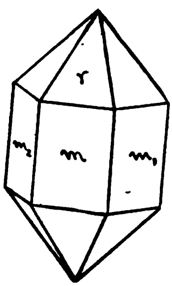

FIG. 10—Quartz.

Specimen No. 31 from Isle Royal Mine, Houghton.

Colorless when pure, often various shades of red, yellow, blue, green and black. Streak, white. Lustre, vitreous, rather greasy. Transparent to opaque. Brittle to tough. Fracture, conchoidal, uneven. Hardness, 7. Special gravity, 2.65. Chemical composition, SiO_2. Oxygen, 53.3%; silicon, 46.7%. Form of crystals, that of Fig. 10.

Quartz is the oxide of silicon and one of the most common of minerals. Owing to its hardness and insolubility in acids and non-weathering properties it forms a large part of many fragmental rocks. It is formed in

three ways (1) by precipitation out of molten magma (specimen No. 104), (2) out of an aqueous solution (vein quartz, specimen No. 31), and (3) as a weathering product of other minerals. Common sands consist chiefly of quartz grains, the indestructible parts of former rocks. Chalcedony is a good example of quartz precipitated from acqueous solution. This form of quartz, if banded, is called agate and if the bands lie in even planes, onyx.

Amethysts are quartz crystals colored red by some foreign substance, usually organic. Opal is an amorphous form of silica, containing variable amounts of water.

A complete analysis of any rock reveals the presence of a certain amount of silica. F. W. Clarke, of Washington, has estimated from careful calculations of many analyses of many kinds of rocks that nearly one-half (50%) of the earth's entire crust consists of silica. Pure quartz is used chiefly for optical purposes. In certain soaps quartz is used for scouring purposes. Flint is a chalcedonic variety of quartz, occuring in limestones and was formerly used by the Indians for knives, arrow heads and other implements.

FELDSPAR (VARIETY MICROCLINE).

Specimen No. 32 from quarry near Republic.

Colorless, white, flesh red, gray. Streak, uncolored. Lustre, vitreous. Brittle. Fracture, conchoidal to uneven. Cleavage, along one plane perfect, along a second somewhat less so. Hardness, 6 to 6.5. Specific gravity, 2.5 to 2.62. Chemical composition, $KAlSi_3O_8$. A complex silicate of potassium, aluminum and some sodium.

Named after its property to cleave. Feldspar embraces a whole series of minerals of similar chemical composition and similar cleavage. The rounded fracture

faces of the pink mineral in specimen No. 32 all result from the feldspar cleavage. With a small chisel and hammer other chips may be broken off exactly parallel to the present faces. Next to quartz, feldspar is the most common mineral. Like quartz it is formed in many different ways but chiefly by crystallization out of a molten magma as in specimen No. 104. Feldspar is not so hard as quartz and is distinguished in the hand specimen from the latter by its cleavage. Specimen No. 104, which contains both feldspar and quartz, is a good example. The glassy particles and grains with irregular fracture and no cleavage scattered through the rock is the quartz, the pink, lath-shaped crystals which flash up and show the flat cleavage faces on turning the specimen in the light, the feldspar. Quartz cannot be scratched with a knife, whereas on feldspar a slight scratch may be produced. Feldspar is used chiefly for the manufacture of porcelain and pottery. In this process a mixture of feldspar and kaolin is used. On subjection to white heat the feldspar melts, cementing the whole together and giving the outer surface the brilliant glaze of porcelain.

MUSCOVITE.

Specimen No. 33 from quarry near Republic.

Colors, various shades of brown, green and yellow. Streak, uncolored. Lustre, vitreous to pearly. Transparent to translucent. Flakes elastic and tough to less elastic and brittle. Cleavage, eminent along one plane. Hardness, 2 to 2.5. Specific gravity, 2.76 to 3.00. Chemical composition, $H_2KAl_3Si_3O_{12}$. A complex hydrous silicate of potassium and aluminum with some magnesium and iron.

Muscovite belongs to the family of minerals called micas, all of which are noted for their perfect cleavage.

Muscovite is almost indestructible and is often found in connection with kaolin, a weathering product of the feldspar. It occurs chiefly in eruptive and metamorphic rocks. A granite is a granular rock consisting chiefly of quartz, a variety of feldspar and micas. The crystals of muscovite resemble flat or columnar hexagonal blocks. In specimen No. 33 they are imbedded in pink feldspar. By means of a knife blade it is an easy matter to lift off from any one of the mica crystals innumerable thin, transparent flakes.

Muscovite is found in certain localities in large crystals, measuring at times 50 centimeters to over a metre across and is then very valuable. The crystals are first cut into suitable blocks, from which thin flakes of varying thickness are cleaved off. Cut mica is valued at $2.20 a kilogramme ($1 a pound), and is used chiefly for windows of stoves and furnaces, also for electrical purposes where transparency, resistance to heat and nonconductivity are needed. Ground mica is used for lubricating purposes, paint, etc. Mica and feldspar are usually found together.

AMPHIBOLE.

Specimen No. 34 from near Republic.

Colorless, various shades of green to black. Streak, uncolored. Lustre, vitreous to pearly, silky in fibrous varieties. Brittle. Fracture, uneven. Cleavage, highly perfect along two prismatic planes. Hardness, 5 to 6. Specific gravity, 2.9 to 3.4. Chemical composition, a complex hydrous silicate of calcium, magnesium, aluminum and other elements.

Amphibole is one of the most important of rock forming minerals. As a constituent of deep-seated and metamorphic rocks it is found in nearly every region of crystalline rocks. It is characterized by good prismatic

cleavage (angle between two cleavage faces is 124 degrees) and the prismatic development of the crystals. Asbestos is a thin, fibrous variety of amphibole; Tiger's eye is an intergrowth of quartz and fibrous amphibole.

SOUTHERN MICHIGAN MINERALS.

The following three minerals, gypsum, celestite and strontianite, from southern Michigan, are chemical precipitates resulting from the evaporation of the inland sea formed by the closing of the outlet to the former bay of the Palaeozoic ocean. Like the Dead Sea and Great Salt Lake of the present age, which are growing gradually smaller and shallower or drying out and precipitating the salt compounds held in solution, the old inland Palaeozoic sea which covered the greater part of Michigan deposited the salt and gypsum beds together with the limestones and shales in which they are found.

GYPSUM.

Specimens No. 35 and 36 from Granville, Kent County.

Color, usually white, often colored by impurities. Streak, white. Lustre, sub-vitreous, cleavage plane pearly. Sectile. Cleavage, eminent along one direction. Hardness, 1.5 to 2. Specific gravity, 2.32. Chemical composition, $CaSO_4+2H_2O$. Hydrous sulphate of calcium.

Gypsum is mined in several districts in Michigan, near Grand Rapids, where a large number of mills are kept in operation grinding and cleaning the raw material; also at Alabaster on Saginaw Bay, where one mill alone produces 240 tons daily, and at St. Ignace in the Upper Peninsula. The gypsum is found interbedded between limestone above and shale and hydraulic limestone below.

It occurs in beds ranging from two to four metres (6 to 14 feet) in thickness and is quarried by blasting into blocks, which are taken to the mills to be crushed and pulverized and prepared for shipment. Gypsum on heating loses one of its molecules of water and becomes plaster of Paris or stucco. It is used largely for decorative purposes, makes the best quality of plaster, is an excellent fertilizer for certain kinds of land. It also serves as a support for large plates of glass during the process of polishing, as a filler for fine paper, as an adulterant in white lead, etc.

Alabaster is a finely crystalline pure form of gypsum, suitable for ornamental purposes, statuettes, etc. Gypsum occurs regularly in connection with salt beds as its mode of formation requires. Satin spar is a fine fibrous variety of gypsum.

CELESTITE.

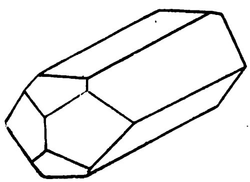

Fig. 11—Celestite.

Specimen No. 37 from Maybee, Monroe County.

Color, white, often bluish. Streak, white. Lustre, vitreous inclining to pearly. Transparent to translucent. Fracture, uneven. Cleavage, perfect along one plane and nearly so along two others. Hardness, 3 to 3.5. Specific gravity, 2.96. Chemical composition, $SrSO_4$. Strontium sulphate.

Named after its sky-blue color. Celestite has very little commercial value. It is characterized by its good cleavage and softness and is rather heavy. It is used chiefly in the preparation of strontium-nitrate employed in fireworks for imparting to the flame (Roman candle balls) a deep crimson color.

STRONTIANITE.

Specimen No. 38 from Ida Quarry, Monroe County.

Color, white and pale shades of various colors. Streak, white. Lustre, vitreous inclining to resinous. Fracture, uneven. Brittle. Cleavage, along two faces nearly perfect. Transparent to translucent. Hardness, 3.5 to 4. Specific gravity, 3.68 to 3.71. Chemical composition, $SrCO_3$. Strontium carbonate.

The strontianite of specimen No. 38 is finely fibrous, exhibits visible crystalform and is contained in the cavities of the limestone. Strontianite, like calcite, effervesces readily with acids but is distinguished by its higher specific gravity and its cleavage. Its commercial uses are limited. Like celestite, it is employed in the pyrotechnic displays to produce red colored fire effects.

CHAPTER IV.

SPECIFIC DESCRIPTIONS OF ROCKS.

The arrangement of the rocks in this collection is a purely stratigraphical one. The rocks are numbered in sequence, according to their respective age. Beginning with those of the Carboniferous period, the youngest in Michigan (Nos. 39 to 48), the geological age of the specimens gradually increases until with Nos. 89 to 105 we encounter the most ancient rocks found in our state. The rocks deposited during the Carboniferous period occupy at present the central part of the Lower Peninsula. See page 57 and map, blue patterns and area marked coal basin. Several of the most important economic natural products of Michigan, such as salt, gypsum, limestone, clays, shale, sandstones and coal, occur interbedded in

this latest series. Unlike the members of the basement complex the Carboniferous rocks have been altered but little since the time of their formation and occur in an easily recognizable form. They are all sedimentary rocks and were formed by deposition and precipitation out of the former Carboniferous sea. One of the last rocks to be formed was the coal. With coal, a rock familiar to all, we shall commence our descriptions. We shall pass from it to other rocks of the Carboniferous period and thence to those of the Devonian, Silurian, Cambrian, Huronian and basement complex eras. As we proceed we shall find that the character of the rocks gradually changes, they soon show the effects of their great age and the vicissitudes through which they have passed. The members of the Huronian group are highly altered while those of the basement complex have frequently been changed to such a degree that we are often unable to decipher their mode of formation, whether sedimentary or eruptive. They belong in the class of metamorphic rocks, the most difficult group of all. In starting with the younger rocks, therefore, we begin with the simpler forms and reach the complex ones only after the way has been prepared for them by a careful study of unaltered products similar to those from which the altered rocks have been derived.

In the description of each rock its mineral composition, the peculiarities of its texture, its geological mode of occurrence, its economic value and other facts which may be of interest will be noted.

ROCKS OF THE CARBONIFEROUS PERIOD.

COAL.

Specimen No. 39 from Jackson Mine, West Saginaw.

Color, black to brownish black. H = 0.5-2.5. Specific gravity, 1.26-1.37. Fracture, conchoidal; splits along bedding and jointing planes. Characterized by burning

with a yellow, smoky flame and not with the blue flame of anthracite. Anthracite contains but few volatile ingredients while bituminous coal emits on distillation large quantities of hydrocarbon oils—tar line compounds. Hence the name bituminous. Its chemical composition varies. Oxygen, 5-15%; hydrogen, 3-5%; carbon, 70-90%.

In Michigan the only coal mined is that of the bituminous variety. Several grades, as steam coal, coking coal and cannel coal are produced. No anthracite or hard coal, has yet been found nor is it likely to be. The area on the map labeled coal basin marks the limits of the coal bearing strata in Michigan. The coal beds, however, do not extend over the region but have only a local development, usually thinning out rapidly. The workable coal seams vary from ½ to 2 meters (1-7 ft.) in thickness and occur interbedded with sandstones and shales, which in turn are usually buried beneath a heavy glacial drift deposit frequently 100 metres (300 feet) thick. According to a conservative estimate of the State Geologist of Michigan, Dr. Lane, 2,000,000,000 tons of coal underlie the coal basin in Michigan, over one-half of which is in workable seams. In the same report the origin of the Michigan coal measures is explained as follows: "The center of lower Michigan was occupied by an arm of the sea, or more likely an independent sea like the Black Sea, opening to the southwest. The land had been higher just previous to the formation of the coal measures and was settling slightly so that the river valleys were flooded like the shore of western Michigan and Monroe County at the present day. The inlets, which are the characteristic of a settling shore and represent the flooded lower parts of river valleys, are often cut off by sand bars and dunes from the main sheet of water. Such are the lakes upon which Benton Harbor, Grand Haven, Muskegon

and Manistee are built. Out from the margin in the bays and inlets may have crept great floating bogs and mats of vegetation, tropical, closely matted, slowly decaying and weighed down by the ever increasing growth above. Occasionally it became overburdened and sank bodily—an accident which happens nowadays to floating peat bogs overgrown with forest—or the waterlogged part dropped bit by bit to the bottom. This green carpet over the water kept pushing farther and farther out and somewhat like the ice forming around the edge of a lake in winter. Like that, too, an occasional storm would drive it back in winrows and perhaps swamp it. This floating forest shed abundant spores and pollen-like powder, which were blown and drifted all over the sea, helping to make a carbonaceous mud, which later became black shale, canned coal or bituminous limestone."

"The rivers contributed their share toward filling up the sound, which may have been shallow, like Saginaw Bay, where the rushes wave from the water thousands of yards from the shore. There were probably minor oscillations between sea and shore, but on the whole for a while the land sank relatively and the sea overlapped unconformably on the land. Then the real level remained fairly constant until the sea was largely filled up. Then the land rose and erosion began."

The coal of specimen No. 39 is bituminous, jet black and brittle and exhibits jointing along several planes. In mining these joint planes are carefully observed and used. It is easier to mine the coal by mining perpendicularly to one of the fracture planes (face, butts, cleats as they are called) than otherwise. In this coal occur frequently small particles of a yellow mineral called iron pyrites or marcasite and consisting of iron and sulphur, which are then more or less detrimental to the coal. The sulphurous odor of the smoke from a locomotive is due

to the presence of sulphide or iron in the coal burned. Such coal is open burning and rarely cokes. Because of the volatile hydrocarbon gases which it contains, bituminous coal deteriorates on long exposure to air.

BLUE SHALE.

Specimen No. 40. Grand Ledge, Eaton County.

The mode of formation of the coal seams in shallow bays and estuaries explains the occurrence of shales, sandstones and limestones either directly above or below the coal seams. Shales are solidified beds of mud and clay which have settled down on the lake or sea bottom. At Grand Ledge the coal seams are interbedded in shales which furnish good impervious roofs for the mining of the coal. The higher the percentage of bituminous matter in a shale the darker its color. Those shales which lie directly above the coal seams are usually jet black and may even grade into pure cannel coal. Such black shales (specimens Nos. 41 and 42) are often mistaken for pure coal. Blue shale, such as solidified blue clay, contains only a small amount of carboniferous matter, if any, is soft, may be easily cut with a knife and shows very distinct fine planes of bedding. If ground to powder, shales make good material for brick manufacture and if mixed with limestone in certain proportions excellent Portland cement. Shale if breathed upon has a argillaceous or clayey smell. If subjected to pressure shales pass into slates, examples of which we shall see later among the metamorphic rocks (page 82).

BLACK SHALE.

Specimen No. 41 from Grand Ledge.

A thinly stratified, soft rock of a grayish black color, occurring with the blue shale above the coal but containing more carbonaceous matter than the former. Its

value, commercial importance and mode of formation are the same as those of the blue shale. The shale was one of the last rocks to be formed in Michigan. From a geological standpoint all the rocks in Michigan are extremely old and ancient. To draw a comparison with history they still belong to ancient geological times. Michigan has been land since the Carboniferous period, no rocks of any extent having been formed during the mediaeval or modern geological times.

BLACK LINGULA SHALE.

Specimen No. 42 from Bay City. Michigan Coal & Mining Co. Above upper coal.

The small, flat, spoon-shaped spots scattered through this specimen are the shells of an ancient organism called Lingula mytiloides, which lived in the sea at the time of the deposition of the black shale and whose hard shells sank to the bottom with the mud and were buried. The shale had undergone very slight alteration since their deposition and the Lingula shells are so well preserved as fossils that we are able to make out their texture even in its minute details. The fine glittering flakes which appear on the flat side of the shale are mica. This particular black shale is so soft that it writes on paper. Finely divided yellow particles of iron sulphide may be observed either disseminated through the rock or grouped in patches. They were formed by the action of decomposing organic matter (albumen) containing sulphur on iron compounds.

IRON CARBONATE AND SPHALERITE.

Specimen No. 43 from Grand Ledge, Eaton County.

Water containing carbonic acid in solution will attack iron bearing compounds and leach out the iron in the form of an acid carbonate. This is deposited later in the form

of a ferrous carbonate, a process analagous to the formation of calcite, described above (page 36). The carbonates of several metals are found among the rocks of the carboniferous age—limestone (calcium carbonate), dolomite, carbonate of calcium and magnesium, and siderite, the iron carbonate are among the most important. Together with the iron carbonate are frequently seen patches of pyrite and marcasite, the sulphides of iron, and sphalerite and the sulphide of zinc.

Iron carbonate is important as an iron ore if found in large quantities. The small amounts which occur in the beds of shales and limestones of the carboniferous strata in Michigan have never yielded iron in paying quantities.

Specimen No. 43 is soft (hardness, 3 to 4) and is characterized chiefly by its extremely high specific gravity resulting from the presence of iron. It effervesces only slightly with cold acid.

SANDSTONE.

Specimen No. 44 from Grand Ledge.

This specimen furnishes conclusive proof even to the most casual observer that the rocks near Grand Ledge were formed by mechanical and chemical deposition in water and are sedimentary rocks. With the unaided eye it is seen to consist of sand grains cemented together and has much the appearance any beach sand would present if consolidated. The cementing material in this case has been largely an iron compound, which is now iron hydroxide or limonite and gives the rock its brown yellow color.

An examination of the specimen reveals the presence not only of quartz sand grains but also of small flakes of muscovite. These minerals are the weathering products of some pre-existing eruptive rock, such as granite, and have been carried away by surface waters and finally

deposited in the sea. In the ocean waters the sand grains sink to the bottom much more rapidly than the fine mud particles, and hence are not carried so far out to sea as the mud and clay. Sandstones were therefore formed near shore, where the pounding action of the waves and moving water was able to carry such coarse material in suspension. Sandstone does not exhibit such perfect planes of bedding or stratification as shales since it was deposited more rapidly and by more turbulent water. Such conditions are less favorable to even distribution and perfect stratification. The mere coarseness of the grains in sandstone precludes very fine planes of bedding. A plane of bedding is a plane of separation between two parts of a rock mass which vary slightly in mineral composition or size of grain. Sandstones vary through all intermediate grades of fineness into aphanitic shale. Certain sandstones (specimen No. 54) make good building stones. The present specimen, however, is too soft and friable to be used for such purposes.

As the size of the grain of a sandstone increases it gradually passes into a rock called

CONGLOMERATE.

Specimen No. 45 from Williamston, Ingham County.

Mud on becoming coarser gradually passes into sand, while the latter grades into gravel. No exact line of distinction is drawn between these different classes of sediments. We all know typical mud, typical sand and typical gravel. We speak of fine sand, coarse sand, fine gravel, coarse gravel, etc., but make in general no sharp division line between the varieties. Similarly shale passes into sandstone and from thence into conglomerate. Conglomerates are consolidated beds of gravel.

The following scheme may aid in rendering these distinctions clear:

SIZES OF INGREDIENTS.	LOOSE.	CONSOLIDATED.
Coarse	Gravel	Conglomerate
to	Sand	Sandstone
fine.	Argillaceous sand	Argillaceous sandstone
	Calcareous sand	Calcareous sandstone
	Clay	Shale
	Marl	Calcareous shale

Conglomerate beds are found only on shore lines and wherever strong currents of water capable of transporting large pebbles have been at work. From their mode of formation it is evident that conglomerates cannot cover large areas but must form comparatively narrow bands following ancient coast lines. They pass rapidly into sandstones as the shore recedes. Specimen No. 45 contains large pebbles of shale and iron carbonate imbedded in a fine matrix of sand. The sand is colored yellow by the iron hydroxide (limonite) deposited between the grains.

LIMESTONE (67% PURE).

Specimen No. 46 from Griffin's Quarry, Arenac County.

The essential characteristics of this specimen are its comparatively high specific gravity, its softness (hardness, 3) and free effervescence with acid. Limestones are either formed by chemical precipitation from solution or are the fragments of shells and calcareous parts of extinct organisms which have settled and accumulated on the ocean bottom and gradually changed into solid rock. The small glittering faces which sparkle on turning the specimen are cleavage faces of calcite (compare No. 25) which crystallized out either at the time of formation of the rock or later.

Limestone if mixed with clay in correct proportion

makes an excellent Portland cement. If heated in kilns the carbonic acid is driven off and unslacked lime (CaO) is left behind. This unites with water with great avidity and forms calcium hydroxide. The carbonic acid in the air then unites with the calcium oxide, and calcium carbonate, the original product, is again produced. At the same time the water which the oxide took up is driven off. This is the explanation of the damp walls in newly plastered houses. Limestones are usually formed some distance from the shore line.

The blue pattern immediately surrounding the coal basin on the map indicates the area covered by the group of rocks to which this limestone belongs.

CHERTY CONCRETIONS (FLINT).

Specimen No. 47 from Griffin's Quarry, Arenac County.

In limestones hard nodular masses called concretions frequently occur. They have been formed by percolating waters which have dissolved minute amounts of silica on their journey and deposited them later at a point favorable for precipitation. They are therefore composed chiefly of flint and chert, tough, compact forms of silicon oxide. If struck a sharp glancing blow with steel, the flint causes small sparks or hot particles of steel to fly, a property used by our grandfathers to produce light. In certain formations these flint nodules assume grotesque shapes, and in older countries, as in England, have given rise to many curious ideas and myths among the common people.

Chert is very hard (hardness, 7), lighter than limestone (sp. gr., 2.65) and does not effervesce with acids. Some of the specimens of No. 47 are mostly carbonate of lime and are then much softer than chert.

SANDSTONE.

Specimen No. 48 from Grindstone City, Huron County.

Horizontal blue pattern region. Lower carboniferous or so-called cold water epoch. This specimen was deposited at a time when the sea covered a much larger area than it did at the time of the formation of No. 45 (Upper Carboniferous). The Palaeozoic sea which at first covered Michigan gradually became smaller and confined to narrower limits. All of the rocks in the Lower Peninsula are sedimentary. We shall find that the few types of sedimentary rocks repeat themselves as we continue. Specimen No. 48 like No. 44 was formed not far from the shore line but at a much earlier date than the sandstone No. 44 described above. The characteristics of these rocks are also slightly different. Color is greenish gray instead of yellow, the size of grain is slightly smaller and the rock is more compact. The presence of muscovite flakes is more noticeable. This sandstone is quarried largely for the manufacture of grindstones. The small quartz grains with hardness, 7 (steel hardness about 6) are the effective material in the process of grinding. The sandstone used for grindstones is taken out of the quarry in blocks and sawed to proper size and shape. In the specimen note the abundance of muscovite flakes parallel to the sawed face (plane of bedding) and their apparent absence on the sides. These flakes at the time of deposition naturally settled down with their flat faces horizontal.

ROCKS OF THE DEVONIAN PERIOD.

The sediments deposited during the Devonian period outcrop at present in areas indicated by the lavendar patterns on the map. They were deposited before the rocks of the Carboniferous period and consequently outcrop

beyond their borders. The Devonian strata consist largely of shales and limestones and are readily eroded by moving water. This is one of the chief causes of the formation of Lakes Michigan and Huron. These two lakes occupy at present the position of the old Devonian strata which have been worn away.

The following specimens have been taken as representatives of Devonian rocks.

LIMESTONE (95% PURE).

Specimen No. 49 from Sibley, Wayne County. Dundee, Corniferous, or Upper Helderberg, Epoch.

External aspect unlike that of specimen No. 62. Soft (hardness, 3), sp. gr. 2.75. Effervesces readily with dilute acid. Cleavage faces of crystallized calcite cause the rock to sparkle if turned and examined in the light. Traces of fossils, the shells of Devonian organisms, are scattered through the rock. This limestone makes good building material owing to its compact, firm texture and non-weathering properties. In Europe many of the famous old cathedrals are built of limestone similar to this specimen. Pure limestones are in great demand in many branches of industry.

DOLOMITE.

Specimen No. 50 from Woolmet Quarry, Exeter, Monroe County. Dundee, Corniferous, or Upper Helderberg, Epoch.

Dolomite differs from limestone in specific gravity (2.86) and its action towards acids. It effervesces only slightly, if at all, with dilute acid. Chemically it is calcium carbonate with magnesium carbonate. The formation of dolomites has long been a matter of controversy

among geologists. In the present case it was probably formed from ordinary limestone by the action of percolating waters which carried magnesium salts in solution. Magnesium carbonate is less soluble than calcium carbonate, and will therefore be precipitated when brought into contact with the calcium carbonate, especially if conditions of high pressure and temperature exist. The magnesium carbonate is deposited in place of the calcium carbonate molecule, which is leached out. Dolomites are excellent building stones.

ROCKS OF THE SILURIAN PERIOD.

The Silurian rocks (red patterns of map) underlie those of the Devonian and Carboniferous periods and form a fringe around the same. The red pattern along the northern borders of Lake Huron and the North and west border of Lake Michigan represent the distribution of the rocks of the Niagara Age (a subdivision of the Silurian). The rocks over which the Falls of Niagara pour are of the same age, hence the name. It is an interesting fact that the rocks directly below the Niagara limestones, the Lorraine and Utica series, which consist chiefly of shales and materials easily eroded by moving water, are covered by water in many cases. The Niagara limestones and dolomites are compact, tough rocks and resist weathering and erosion in a marked degree. Hence the continuous ridge line of islands in Great Bay and in the Thousand Islands. The overlying Monroe series of rock and the underlying series both succumb easily to the erosive and leaching action of moving waters and have been eaten away, leaving only the harder limestones projecting out as chains and islands.

DOLOMITE (GASHED).

Specimen No. 51 from Ida Quarry, Monroe County.

This specimen illustrates well the porous appearance of most dolomites. The small gashes or cavities which cut through the entire rock are a direct result of the mode of formation of the dolomite. As stated above, magnesium carbonate has a higher specific gravity than calcium carbonate and hence takes up less space for a unit of weight. As magnesium carbonate is deposited in place of the original calcium carbonate it does not occupy the space taken up by the bulkier, lighter calcium carbonate, hence the cavities throughout the rocks. This dolomite forms the ridge bounding the northern and western shore of Lake Michigan.

SANDSTONE.

Specimen No. 52 from two and one-half miles S. E. of Scofield, Monroe County. Silvania Sandstone.

A loose, friable sandstone found at the top of the Silurian group of rocks in Monroe County and known as Sylvania sandstone. Color, dark gray. Sp. gr. about 2.65. Too soft and crumbling to be of any value as a building stone but used extensively in glass manufacture. The Libby Glass Works of Toledo require large amounts of pure, clear quartz sand and employ the Sylvania sandstone from Wayne County, Michigan, for that purpose.

ROCKS OF THE CAMBRIAN PERIOD.

The rocks of this period were the first to be deposited from the great Palaeozoic sea and hence consist chiefly of conglomerates, sandstones and shales, the detritus of older rocks forming the basin on which they rest unconformably. The Cambrian areas, labeled sandstone on the map, mark approximately the original coast lines of the

Palaeozoic sea. That part of the Upper Peninsula which is colored yellow and blue (Huronian and basement complex) projected out of the Palaeozoic sea as an immense island. No Cambrian rocks outcrop in the Lower Peninsula. They are at present buried beneath the younger overlying sediments.

A long strip of Cambrian rocks outcrop along Keweenaw Point. The whole copper bearing formation, or Keweenaw series as it is called, is considered by many geologists as belonging to the Cambrian period. This entire series of rocks is one of the most important in Michigan from an economic standpoint and merits therefore special study and description.

The uppermost members of the Keweenaw series are sandstones (see areas marked sandstone on map) which have been placed in the Potsdam division of the Cambrian Age. In the southern and eastern part of the Upper Peninsula the sandstone strata bound the younger strata above and rest unconformably on the older Huronian rocks directly beneath. The Potsdam sandstone outcrops on the southeastern side of Keweenaw Point. The sandstone along the northwestern side is probably an older member of the Potsdam series. The Point proper consists largely of melaphyre lava flows and interbedded conglomerates. These rocks form a series of precipitous ridges, the mean elevation of which is considerably greater than that of the sandstones on either side. This elevation is partly due to a great slip or fault in the formation and partly to the fact that the melaphyres are harder and hence offered greater resistance to erosion. The N. W. side of the Point was forced upwards by orogenic action and the formation cracked along the entire length of the Point, the western side being thrust upward and tilted to a great degree. The exact amount of uplift has never been determined, but along the entire

length of the formation indications of the dislocation are evident.

The lower part of the Keweenaw series of rocks consists of a number of beds of lava with interbedded sandstones and conglomerates. The entire complex of conglomerates and lava flows has been tilted from its original position and at present slopes or dips to the northwest at an angle of 30° to 70° (see cross section). The Keweenaw lava flows were submarine, hence the occurrence of the beds of conglomerate, in some places nearly half a mile thick. The beds of lava vary in thickness from a few feet to four hundred feet. The specimens, Nos. 57 to 62, illustrate the various types of lava rock or melaphyre observed in the copper country. The differences usually betoken some change in the physical conditions under which the rock magma solidified (see Rock Texture, page 12). Those parts of the hot lava which were near the top or bottom of the flow cooled quickly and were under slight pressure. The escaping gases and steam set free by the decreased pressure expanded and formed bubbles and vesicles in the cooling mass. The top and bottom of the lava flows are known by their porous, vesicular appearance. If these gas cavities become filled later with secondary minerals deposited by percolating waters the rock is called amygdaloid (Specimen No. 57). The central part of each lava flow is usually crystalline and free from vesicles and amygdules (specimen No. 58).

Copper occurs in a native state chiefly in fissures, either transverse or parallel to the formation or in the interbedded conglomerates or in the amygdaloidal portions of the lava flows. The same gases and waters which deposited the copper in the amygdaloidal part of the rock deposited it in the conglomerates also. One of the conglomerates, called the Calumet & Hecla con-

glomerate, is very rich in copper, and on it are located the Calumet & Hecla Mine and the Tamarack Mine. The various modes of occurrence will be noted in the special descriptions of the rocks below.

RED SANDSTONE.

Specimen No. 53 from Portage Entry, Houghton County.

This sandstone is quarried on a large scale as a building stone and is sent to many parts of the United States. Its color is due to finely comminuted particles of iron oxide, hematite. If examined with a lens the small grains of the original beach sand may still be discovered in the sandstone. The white round spots which occur here and there are caused by the leaching and discoloring action of organic acids.

The red sandstone is one of the younger members of the Cambrian group and belongs to the Potsdam age.

BROWN SANDSTONE OR BROWNSTONE.

Specimen No. 54 from Marquette Quarries, Marquette, Michigan.

The brownstone quarries at Marquette have furnished material for many of the finest buildings in the cities situated on the Great Lakes. From an aesthetic standpoint the brownstone is preferred by many to all other kinds of building stones. Edifices of brownstone have a substantial, dignified appearance possessed by few others. In the specimen, planes of bedding or stratification are easily recognizable. The brown color is due to the presence of fine particles of iron oxide disseminated throughout the mass.

SHALE.

Specimen No. 55 from Nonesuch Belt, West Hancock.

Strata of shale are frequently found interbedded with sandstone. The character of this shale is not unlike that of the shales described from Lower Michigan. It is a finely stratified, compact, argillaceous, soft rock of a dark gray color. At present it has no commercial value but it might be put to the same uses as the shale of the southern part of the state. In Ontonagon County traces of copper have been found in this black shale. Near Ontonagon a copper mine called the "Nonesuch" was started many years ago in the sandstone, hence the name "Nonesuch" belt.

COPPER BEARING CONGLOMERATE.

Specimen No. 56 from Tamarack Mine, near Calumet.

The mode of occurrence of copper in a conglomerate is well ilustrated in this specimen. It fills the interstices between the conglomerate pebbles, and frequently acts as a cementing material for the same. The amount of metallic copper carried in the conglomerates is usually small, though locally it may be considerable.

The pebbles of the conglomerates and matrix which surrounds them was derived from several varieties of rocks—quartz porphyry, porphyrites, so called felsites—all of which are effusive acid rocks ejected from within the earth's crust by ancient volcanoes.

COPPER IN AMYGDALOID.

Specimen No. 57 from Atlantic Mine, near Houghton.

This specimen is from the top of a lava flow and exhibits the amygdaloidal character described on page 71. The copper fills up the small amygdaloidal cavities,

having been deposited there by percolating solutions. Many minerals, as chlorite, epidote, calcite, prehnite, apophylite and datolite are found associated with the copper in the amygdules. The amygdaloidal part of the lava flow cooled rapidly and hence is fine grained to aphanitic. With the naked eye but few mineral components can be distinguished. As we proceed, however, from the top of the lava flow toward its centre the visible copper decreases gradually, the mineral components increase in size until the rock has the aspect of No. 58.

LUSTRE MOTTLED DIABASE (Ophite).

Specimen No. 58 from Central Mine, Keweenaw County.

This specimen comes from one of the thicker flows which, owing to its resistance to weathering, stands out in a bold, abrupt line of cliffs, locally known as the greenstone ridge.

By turning this specimen in the light cleavage faces in various parts of the piece glisten and reflect the light. On close examination it will be found that the rock consists chiefly of a dark green mineral, pyroxene, which cleaves and produces the above effect. The cleavage faces of this mineral appear spotted or speckled, small dots covering their entire surface. This appearance is due to the intergrowth of the pyroxene with another mineral, feldspar, which produces the lighter specks. Hence the name "lustre mottled." A diabase differs from a melaphyre only in texture, the first consisting entirely of crystallized minerals and the latter exhibiting porphyritic texture, that is, showing larger and older mineral components lying imbedded in a fine compact ground mass. In the diabases but little copper is found. Owing to their nonporosity the rocks are usually fresh and have not been altered to any great extent.

DIABASE.

Specimen No. 59 from West Marquette.

The texture of this specimen is very different from that of the preceding. There the two minerals—pyroxene and feldspar—were intergrown one within the other, and must have crystallized out at about the same time. Here the feldspar crystals were formed first and appear as long, lath-shaped individuals which seem to cut through all other parts of the rock, and gleam when examined in the light. This type of texture is observed only in the diabase and is so characteristic that it is called diabase texture. Diabases are dark, heavy granular rocks exhibiting diabase texture and consisting chiefly of a basic feldspar, with pyroxene and iron oxide. If the cleavage planes of the lath-shaped feldspar crystals be examined with a lens fine lines running parallel to the long direction will be noted. Such lines are called twinning striae and are used by geologists to distinguish soda lime-bearing feldspars from potash-bearing feldspars. Diabases occur in Michigan usually in dike form (page 16). They represent the great feed channels through which the material of the Keweenaw lava flows passed before reaching the surface. In the Gogebic iron range they were largely instrumental in the formation of the immense iron ore deposits found there. Their importance in that respect will be noted in the description of the mode of formation of the iron ores.

GABBRO.

Specimen No. 60 from Mount Bohemia, Keweenaw Point.

The bold rugged cliffs on the south slope of Mt. Bohemia are composed of a coarse-grained, red rock called gabbro, which is intrusive into the melaphyre lava

flows and interbedded conglomerates. From the coarsely crystalline texture it is evident that the gabbro must have cooled slowly beneath the great mass of overlying lava flows and conglomerates, which have been removed by erosion, thus leaving exposed the harder, more durable rock.

In the gabbro the red mineral with the bright cleavage faces is feldspar (page 51) and the dark green, fibrous mineral amphibole (page 53). These two ingredients compose the greater part of the rock and are called essential constituents, for without them the rock would receive another name. At the contact of this gabbro with the surrounding melaphyres small veins of copper ore have been formed and these were formerly mined but were not profitable.

LABRADORITE PORPHYRITE.

Specimen No. 61 from Montreal River, Fish Cove, Keweenaw Point.

This specimen is from one of the surface lava flows of the Keweenaw series. Its texture is typically poryphyritic. Thin tabular crystals of light green feldspar lie imbedded in a compact, aphanitic groundmass. This rock was originally a molten mass far beneath the earth's surface. During its passage to the surface the large crystals or phenocrysts of feldspar were formed, because under such conditions this mineral is less soluble than the others. From the abyssal depths of the first position the thick, viscous, partially crystallized but still hot magma was forced upward and spreading over the earth's surface cooled rapidly. The residual magma solidified quickly and now forms the compact, dark red groundmass which surrounds the green feldspar phenocrysts.

The specimen was picked up as a pebble on the shore of Lake Superior near the Montreal River. The pound-

ing, grinding action of the waves on the angular fragments, broken from the cliffs near by, have rounded off their corners and practically polished the whole.

A rock very similar to this in appearance and mode of formation was used by the ancients for ornamental purposes and was known to them as green, antique porphyry (called "porfido verde antico" by the Italians).

FELSITE (RHYOLITE).

Specimen No. 62 from Bare Hill, north side Bete Grise Bay, Keweenaw Point.

Three highest summits on Keweenaw Point are Mt. Bohemia, Mt. Houghton and Bare Hill. Both Mt. Houghton and Bare Hill consist chiefly of felsite while Mt. Bohemia has for its hard, resistant core the gabbro of specimen No. 60.

Felsite or felsitic rhyolite is an exceedingly compact, aphanitic, effusive rock exhibiting occasional phenocrysts of quartz and feldspar and under the microscope a peculiar groundmass texture. Felsites are tough and resist all weathering and erosive agencies to a remarkable degree. The specimen No. 62 has been ground and polished by long continued wave action. Had the felsites cooled more slowly ordinary granite would have been formed. The beds of conglomerate from which a large part of the copper is obtained consist almost entirely of felsite pebbles cemented together. Considering the thickness of some of the conglomerate beds (up to half a mile thick) and the length of time necessary for water to polish one layer of pebbles an idea of the extent of time for the formation of the conglomerate beds may be obtained.

The red color of the felsites is due to particles of red iron ore (hematite) disseminated throughout the mass.

ROCKS OF THE PRECAMBRIAN PERIOD.

HURONIAN ROCKS.

The Huronian rocks contain the enormous deposits of iron ore which have made the Lake Superior region the leading iron ore producer. Hence they are often called the iron bearing group. From the time of the discovery of iron ore in Michigan to 1900 inclusive, over one hundred millions (104,000,000) long tons of iron ore were shipped from the mines in Michigan alone.

The character of the rocks constituting the Huronian group varies greatly. They have all been subjected to a greater or less intense metamorphic action and do not now appear in their original state. A large number exhibit a well developed, schistose or banded texture and accompanying secondary metamorphic minerals. Schistose rocks are named after the predominating minerals which appear in the rock. A schist consisting of mica and quartz is called a mica schist, if garnets be present a garnetiferous mica schist, etc.

In the Upper Peninsula, iron ore is found in several different districts or ranges—the Penokee-Gogebic Range (near Wisconsin), the Marquette Range, the Crystal Falls Range and the Menominee Range. The rocks from one range bear close resemblance to those of any other. Specimens have, therefore, been collected only from the Penokee-Gogebic Range and the Marquette Range.

GOGEBIC IRON RANGE.

The geological structure of the Penokee-Gogebic Range is such that the Keweenaw series overlies the iron bearing series unconformably—both series dipping, however, to the northwest—the entire region having been tilted after the Keweenaw period. The entire iron bear-

ing formation of the Gogebic Range is divided into three members:

The upper slate member.

The iron bearing member.

Quartz slate and quartzite member.

These three members comprise the Upper Huronian. They rest uncomformably on the Lower Huronian and Basement Complex. The Lower Huronian is represented by quartzite and a cherty carbonate member.

The following five specimens illustrate a few of the many rock types found in this district.

GRAYWACKE.

Specimen No. 63 from half a mile north of Ironwood.

A compact, hard, gray rock occurring as a member of the upper slate member of the iron bearing formation. The graywacke was originally soft, gritty clay and mud deposited on the ocean bottom and has since become hardened and gradually metamorphosed. With it true slates are found in great abundance. These upper slates and graywackes lie directly above the iron bearing series, the uppermost portion of which are cherty iron carbonates and cherts similar to specimen No. 64.

CHERTY IRON CARBONATE.

Specimen No. 64 from Palms Mine, Bessemer.

The original rock from whose alteration all the ore deposits in Michigan were derived is found in an unchanged condition in several of the iron ore ranges. It consists then of a fine grained mass of carbonate of iron and silicon dioxide in the form of chert. They were both derived from the ancient Huronian sea which covered this land at one time. The usual colors of the cherty iron carbonates are dark shades of gray. Characteristic is

their high specific gravity. Their weight alone is usually sufficient to distinguish them from other sedimentary rocks. They have no common commercial value at present but may in the future be used as a source of iron ore.

CRYSTALLIZED CHERTY IRON CARBONATE.

Specimen No. 65 from Montreal River, Ironwood.

No. 65 differs from the preceding specimen in texture but not in composition. This specimen originally had the aspect of No. 64 but was changed to its present state by dynamic action. The iron carbonate under the influence of great pressure recrystallized and formed large crystals, the chert material accumulating at the same time in patches. At present the rock consists of granular, soft, cherty iron carbonate with particles of chert or flint disseminated throughout the mass. The chert is very hard and cannot be scratched with the knife, whereas the carbonate has only the hardness, 3 to 4, and yields readily to the blade. The alteration of these cherty iron carbonates produced the immense ore deposit found with the Huronian strata. The ores from the Penokee Range resemble those from the Marquette district so closely that only ores from the latter range have been included in the collection.

QUARTZITE.

Specimen No. 66 from south of Brotherton Mine, Wakefield.

Quartzite is a hard, compact, metamorphic alteration product of sandstone. Traces of the original granular texture are still visible in specimen No. 66. This rock occupies a position near the top of the quartzslate member, which assumes a more massive phase here, than toward the western end of the range.

MICACEOUS QUARTZ SLATE.

Specimen No. 67, Palms Mine, Bessemer.

The iron bearing member of the Penokee group is underlain by a quartzslate foot wall which is impervious to percolating waters and was largely instrumental in the formation of iron ores. Primarily soft clay and mud, it has developed by pressure and heat into the present fissile, finely stratified slate. The particles of mica are confined to parallel beds and seldom lie with their flat faces at angles to the planes of bedding. All possible gradation phases between the quartzite No. 66 and the micaceous quartz slate occur.

MARQUETTE IRON RANGE.

The Huronian group of the Marquette district consists of three distinct periods, each separated one from the other by a great unconformity. The groups are divided as follows:

Upper Huronian	Michigamme slate member. Bijiki schist member (Iron-bearing). Ishpeming and Clarksburg tuff member.
	Unconformity.
Middle Huronian	Negaunee member (Iron-bearing). Siamo slate member. Ajibik quartzite member.
	Unconformity.
Lower Huronian	Wewe slate member. Kona dolomite member. Mesnard quartzite member.

The divisions are usually named after some locality near which the rocks of that age are well developed. Thus the Michigamme slate formation is found in characteristic exposures along the shores of Lake Michigamme.

ROCKS OF THE UPPER HURONIAN.

MICHIGAMME SLATE FORMATION.

This formation consists chiefly of slates and their metamorphic alteration products.

STAUROLITE MICA SCHIST.

Specimen No. 68 from south side of Lake Michigamme.

The specimen consists essentially of fine mica flakes which serve as a background and coating for the larger crystals of staurolite, a hard gray to red silicate. The schistose texture of the rock indicates its mode of formation. These minerals have been developed by the long continued metamorphic action to which the original material was subjected.

GARNETIFEROUS MICA SCHIST.

Specimen No. 69 from Kloman Mine, Republic.

In this rock garnet crystals have been developed in place of the staurolite of the preceding specimen. The small faces of the garnet crystals, similar to those of specimen No. 12 (page 40) should be noted. The mica constitutes the larger part of the rock—its small flakes enveloping the garnet crystals and rendering the schistose character of the rock very pronounced.

BIJIKI SCHIST FORMATION.

GRUNERITE MAGNETITE SCHIST.

Specimen No. 70 from West Champion.

In the Gogebic Range the upper slate member was underlain by the iron bearing member and that in turn by the quartz slate member. The succession in the upper Marquette is essentially the same. Below the wide belt of slate described above (Nos. 68 and 69) an iron bearing member is found which in an unaltered condition is a cherty iron carbonate similar to the original rock in the Geogebic Range. If this carbonate be subjected to pressure and heat, metamorphic rocks result, one type of which is illustrated by the present specimen. The original bedding of the cherty iron carbonate is still recognizable. It is almost impossible, however, to cleave the rock in that direction at present. The new minerals which have formed (grunerite needles, an amphibole with the formula $FeSiO_3$) extend from one plane to the adjacent one and form an interlocking mass which is extremely tough and difficult to break. The original high specific gravity is retained in the metamorphosed rock. Grunerite magnetite schists are characterized by fine needles of grunerite radiating in all directions and imbedded in a groundmass of magnetite. Grunerite magnetite schists are not used for commercial purposes. The iron they contain is in part chemically united with silica and difficult to extract. The rock is named Bijiki schist by geologists after typical exposures of the same found on the Bijiki River.

LIMONITE.

Specimen No. 71 from North Champion.

This specimen was described as a mineral on page 32.

It represents another phase of alteration of the original cherty iron carbonate. Percolating water and atmospheric agencies have produced the change. The original ferrous carbonate was oxidized by oxygen bearing waters and iron hydroxide and the oxide precipitated. At the same time part of the silica was removed and part of it recrystallized. Observe the small geode like cavities which are lined with fine sharp quartz crystals.

GRAPHITE SLATE.

Specimen No. 72, Bijiki formation, West Champion.

Interbedded with the above alteration products of cherty iron carbonates we find in certain localities black graphitic slate of the general character of No. 72. With the unaided eye no mineral components except a few scattered, glistening flakes of graphite and mica are visible. The rock presents a dull black, lustreless aspect. Its cleavage is not perfect enough to produce a good roofing slate.

CLARKSBURG TUFF.

Specimen No. 73, one-quarter mile west of Stoneville Station.

During the period of deposition of the Michigamme slates and the Bijiki schists and even down into the Goodrich quartzite age, described below, there occurred volcanic eruptions, the ashes and other ejectamenta of which settled down in the water and were intermingled with sedimentary material. In this specimen ash fragments may be seen at several points. A rock which consists of

fragments of volcanic ash cemented together with or without foreign sedimentary material is known as volcanic tuff. The best examples of the Clarksburg tuff outcrop near Clarksburg. A mere glance at specimen No. 73 suffices to note its peculiar, fragmental character. The greater part of the rock is at present a chloritic schist.

ISHPEMING FORMATION.

GOODRICH CONGLOMERATE.

Specimen No. 74 from three-quarters of a mile south of Stoneville Station, Saginaw Location.

The base of the upper Marquette series is often a conglomerate rich in iron ore. The iron ore fragments of the conglomerate were derived in a large measure from the underlying Negaunee formation, the iron bearing member of the middle Huronian period. Formerly a loose aggregate of gravel and ore fragments, the mass has been pressed and squeezed and sheared to such an extent that a schistose structure has developed. The iron ore grains have been dehydrated and rolled out into thin flakes which glisten and sparkle like muscovite laminæ. Barring its metallic lustre the rock closely resembles a mica schist. The angular quartz fragments lie enclosed in a filling of sheared iron ore flakes. Wherever a true conglomerate is found the former shore line is not far distant. The Goodrich conglomerate at the base of the upper Huronian formation separates it from the middle Huronian and is one of the evidences of the great unconformity which exists between the two formations. After the uppermost member of the middle Huronian formation had been deposited the land rose and the sea receded and a period of erosion set in. The sea again transgressed and the basal or Goodrich conglomerate of the upper Huronian was formed.

At several points, Champion, Republic, Ishpeming, etc., the ore bodies rest partly in the basal portion of the Goodrich quartzite and partly in the next underlying formation, the upper member of the middle Huronian series, and thus weld two unconformable series together.

CHLORITE SCHIST.

Specimen No. 75 from Michigamme Mine, Michigamme.

The specimen is a highly altered metamorphic rock composed principally of chlorite with crystals of garnet and martite disseminated throughout the mass. From the structural relations of the adjacent rocks it is probable that this rock is an extreme metamorphic product of an eruptive rock—diorite, to be described below. The schistose texture indicates the metamorphic condition of the rock. From this rock the large garnet crystals described on page 40 were broken out. The garnet, martite and chlorite are all metamorphic products resulting from the alteration of pre-existing minerals.

ROCKS OF THE MIDDLE HURONIAN.

The middle Huronian series has been divided into three distinct members:

1. Negaunee or iron bearing member;
2. Siamo slate member;
3. Ajibik quartzite member.

The predominating rocks in the Negaunee formation are cherts, jaspilites and iron ores. The Siamo slate member consists chiefly of black slates with interbedded quartzites. The Ajibik quartzite member is mostly quartzite with a basal quartzite conglomerate indicating an unconformity between the middle and lower Huronian series.

NEGAUNEE OR IRON BEARING FORMATION.

By far the larger percentage of iron ore from the Marquette district has been derived from the Negaunee formation. The ores occur in several different forms and have been classed as soft ore bodies and hard ore bodies. The former are situated entirely within the Negaunee formation, while the hard ore bodies are found at the top and extending up into the Goodrich quarzite above. In the formation of the ores the eruptive rocks called diorites were instrumental in the formation of and frequently acted as a foot wall for the ore bodies.

DIORITE.

Specimen No. 76 from Cleveland Lake Mine, Ishpeming.

The vicinity of Ishpeming and Negaunee presents to the observer an unusual aspect. Scattered throughout the entire district steep hills and bluffs of varying height rise abruptly and produce an exceedingly rough, difficult country. The hills are made up of intrusive diorite sheels and bosses which have withstood weathering and erosion better than the original enclosing rock and hence stand out at present as "diorite knobs." As molten intrusive material they were forced up into the sedimentary rocks of the Negaunee formation, and there cooled slowly, forming rather coarse grained, dark colored, heavy rocks consisting chiefly of feldspar and amphibole (page 53). The cleavage faces of the dark, almost black, amphibole gleam as the specimen is turned and examined in the light. The diorites are tough, dense rocks, almost impervious to circulating underground waters. The ore bodies have been concentrated in their present position by the action of percolating waters, and hence are often found just above the impervious diorites. The underlying diorites have

frequently been altered to a soft, red colored, soapy rock called paint rock by the miners, who regard its presence as a very favorable indication of ore. Paint rock is practically impervious to water.

SLATE ORE.

Specimen No. 77 from Pittsburg & Lake Angeline Mine, Ishpeming.

The principal ore of the Marquette Range is hematite. As above noted the hematite occurs in various forms and the ore is known either as soft ore or hard ore. Specimens Nos. 77 and 78 illustrate two varieties of the hard ores. The soft ores crumble so easily that good hand specimens cannot be obtained. They resemble dark red or brown earth but may be distinguished from it by their high specific gravity. The larger part of the hard ores was derived originally from the soft ore bodies which were subjected to dynamic metamorphic action. The slate ore consists essentially of fine, micaceous, leaf-like hematite flakes with a few comminuted quartz grains. The ore is of the best quality and contains nearly 70 per cent pure iron.

MICACEOUS ORE OR SPECULAR HEMATITE.

Specimen No. 78 from Champion Mine, Champion.

Another form of the hard ore. In this case the soft ore was sheared by dynamic action to such an extent that the hematite grains were rolled out into thin flakes, all nearly parallel one to another, thus giving the ore its specular, tinsel-like appearance. Fine grains of quartz are occasionally found in the mass. The schistose character of the rock is very pronounced.

JASPILITE OR HARD ORE JASPER.

Specimen No. 79 from Ishpeming.

The original rock from which all the ore was derived is a cherty iron carbonate (specimen No. 82). The original character of this cherty carbonate has been remarkably changed by weathering, percolating waters and dynamic action. The phases of alteration are shown by the three specimens Nos. 79, 80 and 81. To reach its present state the rock No. 79 passed through the following alterations: The ferrous carbonate of the original cherty iron carbonate (No. 82) was oxidized and soft iron oxide produced. At the same time or later a rearrangement of the chert and iron ore bands took place, this forming the soft ore jasper (No. 80). By the action of oregenic forces the soft ore jasper was changed to the hard ore jasper of this specimen. The same process produced the hard, specular ores. The hard ore jasper (No 79) occurs in conjunction with the hard ore bodies and was formed invariably near the eroded surface of the Negaunee formation. This is shown by the perfect oxidation of the original carbonate. The brilliant red bands consist of red jasper or chert colored by finely diffused hematite flakes. Between the chert bands hard specular ore occurs. The history of the formation of No. 81 is different and will be given with the description of that specimen.

On a bright sunny day the bare hills of this hard ore jasper southeast of Ishpeming present a brilliant, splendent appearance. The bands of light red jasper with the interbedded laminae of specular iron ore are often folded, bent and contorted in the most fanciful fashion. The bands of jaspar are frequently broken and pressed out of place.

SOFT ORE JASPER (CHERT).

Specimen No. 80 from Negaunee.

Soft ore jasper is found below the hard ore jasper and occupies the middle horizon of the Negaunee formation. Its mode of formation as an alteration of the original cherty iron carbonate is described above. The soft ore bands have fallen away on trimming the specimen. Thin, film-like remnants of the soft ore may still be seen on the flat sides. The chert which occurs with the soft ore is put to no economic use.

MAGNETITE GRUNERITE SCHIST.

Specimen No. 81 from Champion.

This rock is a deep-seated form of alteration of the cherty iron carbonate. The great heat and pressure to which it has been subjected has driven off the carbonic acid gas and has affected the crystallization of the iron silicate, grunerite, while the remaining iron has been oxidized to magnetite in the absence of superabundant oxygen.

The original banded texture of the rocks is not so apparent here as in the magnetite grunerite schist phase of the Bijiki schist (No. 70, page 83). The magnetite in both these rocks and in the jaspilite is noticeable by its effect on a compass needle. It is a metamorphic product and its presence led to the early discovery of iron ore in Michigan. The large soft ore bodies containing frequently many millions of tons of ore are but slightly magnetic, if at all, and probably would not have been discovered so easily had not the way been pointed by the magnetite of the metamorphic schists, which are at present considered worthless.

ORIGINAL CHERTY IRON CARBONATE.

Specimen No. 82 from Barnum Mine, Ishpeming.

This cherty iron carbonate is essentially the same as No. 64, from the Gogebic Range, described above. The slight differences may be observed by comparing the two specimens. Mode of formation and composition of both is similar in all respects.

SIAMO SLATE.

Specimen No. 83, Barassa Mine, Negaunee.

The cross section shows the next underlying formation below the Negaunee to be the Siamo slate. The planes along which the rocks cleave most readily at present were produced by metamorphic action. The original planes of stratification may be seen running at an angle across the cleavage planes. The rock, however, no longer splits parallel to the bedding as in the original shale. In all slates such secondary cleavage planes developed by pressure are more prominent than the original planes of deposition and give the rock its peculiar fissility. The Siamo slates were deposited in comparatively deep water.

AJIBIK QUARTZITE.

Specimen No. 84 from Carp River, near Marquette.

The Ajibik quartzite, an old metamorphic sandstone on which the Siamo slates rest, was formed near the shore as beach sand. Just below the Ajibik quartzite a great unconformity exists. Before the deposition of the quartzite the land was uplifted, the sea receded and a period of erosion set in. During this process the underlying formations were deeply eroded. Later the land again subsided and the sea transgressed. The first sediments to be deposited were the sands of the Ajibik

quartzite. At the base of the Ajibik quartzite a basal conglomerate is found. This contains pebbles of the underlying sedimentary rocks, thus indicating the unconformity. The forces which aided in changing the sandstone into quartzite tilted the original horizontal beds and at present they form a trough, as indicated in the cross section.

ROCKS OF THE LOWER HURONIAN.

The lower Huronian formation has been divided into three members:

1. Wewe slate member;
2. Kona dolomite member;
3. Mesnard quartzite member.

The Wewe slates are the youngest members of the formation and form the uppermost layers. They pass gradually into the Kona dolomites and through them to Mesnard quartzites.

WEWE SLATE.

Specimen No. 85. Fault on Carp River, near Marquette.

This black slate covers a large area southwest of Marquette. Its characters are the same as those of the slates described above. Small, scattered flakes of mica may be seen on the cleavage planes.

KONA DOLOMITE.

Specimen No. 86 from east side of Mesnard Bluff, south of Marquette.

Dolomite differs from ordinary limestone only in chemical composition, part of the calcium carbonate having been replaced by magnesium carbonate. The

Kona dolomite has furthermore been pressed and altered to a certain extent so that at present its resemblance to the dolomites of Lower Michigan is rather vague. It is more highly crystalline than those previously described. Specific gravity and hardness have remained unchanged. By the pressure a more or less schistose structure has been developed.

KONA SLATE.

Specimen No. 87 from Mt. Mesnard, south of Marquette.

The lower portion of the Kona dolomite member consists of slate with some interbedded dolomite and cherty quartzite. The specimen represents the general appearance of the slate.

MESNARD QUARTZITE.

Specimen No. 88 from Mt. Mesnard, east of prison, south of Marquette. Mt. Mesnard was named after Rene Mesnard, one of the first Europeans to explore Lake Superior.

This quartzite is similar to the Ajibik quartzite, described above. Traces of the original sandstones, however, not so noticeable. Schistosity often well developed. A hard, tough, schistose, light-colored rock consisting almost entirely of quartz. The Mesnard quartzite passes at its base into a slate and slate-conglomerate containing pebbles of the underlying basement complex rocks. The Mesnard slate and quartzite was the first formation to be deposited by the Huronian ocean. The basement complex rocks subsided gradually and the Huronian ocean transgressed, covering the area. Meantime the exposed rocks of the basement complex were eroded. From the resulting detritus the Mesnard series was formed.

ROCKS OF THE BASEMENT COMPLEX.

The rocks formed during the basement complex era are the oldest in Michigan. Without exception they show evidences of the pressure and changes they have undergone. In several instances (specimens Nos. 94, 95 and 96) they have been altered to such an extent that as yet we do not know conclusively whether they represent old altered sedimentary rocks or eruptive rocks.

PALMER GNEISS.

Specimen No. 89 from southwest of Palmer, near Negaunee.

A fine grained, light gray, schistose rock consisting chiefly of small flakes of mica, feldspar and quartz. The mineral components are small but they can be distinguished without the aid of a pocket lens. The rock has suffered such intense metamorphism as to render its origin doubtful. It may be an altered eruptive rock or even a part of the sedimentary series changed and indurated by the adjacent intrusives. A portion of the so-called Palmer gneiss is certainly only an altered portion of the Siamo slate, intruded by Huronian granite.

TALC AND SERPENTINE.

Specimen No. 90 from Ropes' Gold Mine, Ishpeming, Mich.

The alteration of this specimen can be traced out step by step from its original condition. Specimen No. 93 below is the original eruptive rock from whose alteration specimens Nos. 90, 91 and 92 have resulted. Specimen No. 90 consists chiefly of two minerals, serpentine and talc, intimately intergrown. The schistose structure of

the rock is noticeable on the broken side of the specimen. The rock is so soft that it may be cut with an ordinary saw or knife. It is used chiefly as the soapstone of commerce. The quality does not warrant its use for ornamental purposes.

ALTERED PERIDOTITE (IRON ORE, DOLOMITE AND SERPENTINE).

Specimen No. 91 from Presque Isle.

This specimen is composed essentially of iron oxide and serpentine intersected by veins of dolomite. They are the weathering products of the original components of the peridotite. The zone of surface weathering, however, does not extend down to a great depth. If a deep shaft were to be sunk in the peridotite we would find all stages of alteration from this specimen down to the less altered variety of specimen No. 93. Nature has, however, exposed the different stages for us. Ages ago after the peridotite which was then exposed had altered to its present condition, a fault or crack severed the mass into two parts, the eastern portion being forced upwards until the displacement amounted to hundreds of feet. As the upheaval took place the top of the rising half was gradually cut down by erosion to a level with the western portion. We are thus able to see the highly altered and less altered forms of the peridotite side by side, the first on the west and northwest sides of Presque Isle, the latter on the northeast side, where they are known locally as the black rocks.

SERPENTINE (VARIETY VERDE ANTIQUE).

Specimen No. 92 from one-half a mile southwest of Ropes' Gold Mine, Ishpeming.

A green variety of serpentine altered from peridotite, similar to No. 90 but without talc. Large slabs of

verde antique are used in buildings for decorative purposes. Ornaments such as inkwells, pedestals, etc., are also made from it. Within the mass veins of fibrous serpentine are occasionally found and if wide enough are mined, furnishing the commercial asbestos. The Michigan serpentine has not as yet been utilized.

PERIDOTITE.

Specimen No. 93 from Presque Isle, Marquette.

In the hand specimen so few mineral components can be seen that it requires a trained eye to distinguish them. The rock is characterized chiefly by its dark black color, its high specific gravity and lustre-mottled appearance. Small cleavage faces of the mineral enstatite sparkle as the specimen is turned in the light.

KITCHI SCHIST.

Specimen No. 94 from south end of Deer Lake, Ishpeming.

The five specimens (Nos. 94, 95, 96, 97 and 102) are schistose rocks which cover a large portion of the basement complex area. They are the oldest and most highly altered of this group. They are cut by dikes of the eruptive rocks (Nos. 98-101 and 103-105). The so-called Kitchi schists are found north of Ishpeming and Negaunee. To the eastward they grade into the Mona schists, whose chief area lies north and west of Marquette. The names Kitchi and Mona are local and are applied because of slight differences in the texture of the rocks, which are not well shown in the present hand specimens. The Kitchi schists usually contain pebble-like components which are not found in the Mona

schists. Kitchi schists are highly schistose, heavy, green, aphanitic rocks with a peculiar sheen in reflected light. The green color is due to the mineral chlcrite, small particles of which are disseminated throughout the mass.

MAGNETITE SCHIST.

Specimen No. 95 from between Pine and Spruce on Ohio Street, Marquette.

Large ore bodies have never been discovered in the basement complex rocks of Michigan. In Minnesota, however, the enormous deposits of the Vermillion Range are situated within basement complex rocks. Near Marquette at several localities ore occurs in bands running parallel to the planes of cleavage cr strike of the schists. It is usually magnetite or hematite. Specimen No. 95 illustrates its aspect and general slaty character. Small seccndary veinlets may be seen cutting across the specimen in various directions.

BASIC MONA SCHIST.

Specimen No. 96 from corner Ohio and Front Streets, Marquette.

Schistosity well marked. Mineral ccmponents hardly distinguishable by the naked eye. Quartz may be seen in patches. The green color is due largely to amphibole and not to chlorite as in No. 94. All of these green metamorphic rocks were formerly greenstones, a general name in use even at the present time. Called basic Mona schist because of its low percentage of silican dioxide (SiO_2). The basic character is indicated by its high specific gravity.

MASSIVE MONA SCHIST.

Specimen No. 97 from Champion Street and Whetstone Brook, Marquette.

Another phase of the Mona schist in which the schistose structure is not so well marked. The mineral and chemical composition of these basement complex schists varies greatly. They are almost without exception so fine grained that it is difficult to distinguish their various mineral constituents with the unaided eye. Their study and classification is a matter of microscopical investigation. In the massive Mona schist the green color results largely from finely disseminated epidote grains and not from chlorite or amphibole.

AMPHIBOLITE.

Specimen No. 98 from Partridge Island.

The rock is coarse-grained and consists principally of amphibole (page 53) as an alteration of pyroxene and red alteration products of feldspar. Traces of the original pyroxene may still be observed in the central portion of many of the amphibole crystals. The amphibolite occurs in the form of large dikes or bosses intruding into the surrounding Mona schists. Note the high specific gravity and the bright cleavage faces of the amphibole. The texture is entirely different from that of any sedimentary rock. From its geological mode of occurrence we know it to be eruptive, the texture alone indicates this, and also that the molten magma must have cooled very slowly to form such a coarse-grained rock. In the determination of rocks, the mode of occurrence, the mineral components, chemical composition and the texture are the four factors used. Ordinarily two of them suffice to place the rock approximately, but for accurate work all four should be known.

DIORITE.

Specimen No. 99 from Picnic Rocks, Marquette.

Qualitative mineral composition essentially the same as that of No. 98. More feldspar is present, however, and the amphiboles present a different aspect. They are darker in color and compact, not fibrous. The diorites resist erosion and weathering to a much greater degree than the Mona schists, into which they forced their way as bosses and dikes. Hence they usually appear as knobs or smooth and rounded hills towering above the plains—or as small bare islands dotting the bays and shallow waters of Lake Superior near Marquette.

This diorite consists entirely of crystallized minerals arranged according to laws governing eruptive rocks. Color, dark; grain, coarse; specific gravity, high.

SYENITE PORPHRY.

Specimen No. 100 from Middle Island, Marquette.

With the unaided eye the dark purple red rock appears to consist of larger crystals of feldspar (acid oligoclase) imbedded in a finer grained matrix of the same general color and apparently same mineral composition. On turning the specimen in the light long, narrow, lath-shaped cleavage faces of feldspar may be observed. Syenite porphry occurs in the form of narrow dikes intruding into the Mona schists and granites.

SYENITE.

Specimen No. 101 from six miles northwest of Marquette.

Syenite is a deep-seated rock consisting chiefly of a light colored feldspar and some dark colored component. The large amount of feldspar present gives the rock its

light grayish red color. The feldspar occurs in the form of small grains and is distinguished from the dark colored amphibole by its color and cleavage. The specific gravity of syenites is lower than that of diorite. This syenite occurs in the form of large bosses intrusive into the Mona schists. The syenites are largely used as building and monumental stones. The ancient Egyptians built the pyramids and obelisks of syenite blocks, which they obtained from quarries at Syene—the modern Assuan—on the Nile in Upper Egypt.

ACID MONA SCHIST.

Specimen No. 102 from north of old Polyglonal Works, Marquette.

In the Mona schist area narrow belts of lighter, more acid schists containing a larger percentage of silicon dioxide (SiO_2) are found. Their general appearance is that of No. 102. Highly schistose and fine grained to aphanitic. On close observation larger crystals of quartz and feldspar may be seen imbedded in an aphanitic background. The acid Mona schists often have a greasy feel. They are supposed to be metamorphosed acid eruptive rocks—either dikes or lava flows.

APLITE.

Specimen No. 103 from corner Fifth and Prospect streets, Marquette.

The aplites of the basement complex occur as narrow dikes breaking up through the granites and schists. They are extremely fine grained, light gray colored rock in which larger crystals of quartz and feldspar may be distinguished with the unassisted eye, the quartz in the form of occasional glassy grains, the feldspar in broad crystals

exhibiting flat cleavage faces. Note the fine particles of yellow pyrite disseminated through the entire rock. The aplites of the basement complex are often gold bearing but rarely in paying quantities.

GRANITE (COARSE-GRAINED).

Specimen No. 104 from Newport Mine, Ironwood.

The essential constituents of granite are quartz and light feldspar (alkali feldspar). Granites are light colored rocks and differ from syenites only in the presence of quartz, both being deep-seated rocks. The texture and mode of formation are the same. With the quartz-feldspar mixture small flakes of dark mica are found. Much of the feldspar has lost its fresh unaltered appearance. Its cleavage faces are dull, the mass appears to be earthy. As a result of its exposure to weathering agencies the feldspar has altered to a mixture of kaolin and quartz. Granite makes first-class building material and granite soil excels all others from an agricultural standpoint.

Specimen No. 104 from Ironwood is from the basement complex of the Gogebic Range.

GRANITE (FINE GRAINED).

Specimen No. 105 from Middle Island, near Marquette.

Specimen No. 105 differs from No. 104 chiefly in the size of its grain. Colored constituents are also more abundant. Quartz and feldspar, however, form the chief part of the rock. The colored constituents are more or less altered. The green mineral is mostly chlorite, an alteration product of original mica and amphibole. The red color of the feldspar is due to enclosed oxide of iron

(hematite) in the form of microscopic particles. The granites form vast areas in the basement complex regions. In the Marquette region they are younger than the Mona and Kitchi schists, desribed above, and frequently contain inclusions of them.

CHAPTER V.

MINING AND TREATMENT OF ORES IN MICHIGAN.

COPPER.

The greater part of the copper mined in Michigan occurs as native copper. It is found usually disseminated in small particles throughout the enclosing rock. Specimens Nos. 56 and 57 were chosen particularly to illustrate its distribution within the two types of vein material, the conglomerate and the melaphyre. The copper appears to have been concentrated along certain conglomerate beds and melaphyre lava flows and to be absent in others. The lode therefore follows along the bed or lava flow. The process of mining consists essentially in breaking out the vein or lode rock by blasting and hauling it to the surface. It is the duty of the mining engineer to devise methods to attain this end in the simplest and most economical manner possible. He has also to deal with the means of ventilating the mine, and to adopt suitable devices of various sorts. Fortunately the copper mines are remarkably dry and require but little pumping of mine water.

In certain of the deep mines the copper lodes have been followed downwards for over 6000 feet and still the value of the vein rock is so high that it pays to construct powerful engines to lift the rock in skips carrying several

tons of ore from the lowest levels of the mine to the surface. From the mines the rock is transported to the stamp mill where it is first crushed and then passed over various machines which separate the heavy copper from the lighter rock substance. The principle underlying all such rock separation is the same; in running water heavy material sinks to the bottom while the lighter rock fragments are carried forward and off. Moving water is and always has been the chief agent in ore separation. Even the ancient Greeks were acquainted with this method. The myth of the Golden Fleece is based on the fact that sheep's skin and fur was originally used to collect the small grains of gold as they sank to the bottom in the process of washing gold from the placer deposits. From the stamp mills the copper concentrates which still contain some impurities are sent to the copper smelters where they are refined, cast into bars, ingots, etc. The product is then shipped to the wire and rolling mills where it is fashioned into the various articles in use at the present time—into copper wire, copper sheeting, bars, etc.

IRON ORE.

Unlike the copper, iron is not found in Michigan in its native state. Iron ores are essentially chemical compounds of pure iron, oxygen and hydrogen in variable proportions. The iron ores occur in pockets and lenses in the rocks of the iron bearing members. They are mined by methods not dissimilar to those of copper mining. Owing to a different mode of formation, however, the iron ore bodies do not extend to such great depths as the copper veins and are less regular in shape. The deepest iron mines in Michigan are not over 1500 feet deep. The iron ore as taken from the mines is transported directly from the mine to the blast furnaces where

it passes through a series of reducing and refining processes until eventually pig iron is obtained as the final product. Several large charcoal blast furnaces are located in the Upper Peninsula, one at Marquette and another at Gladstone. By far the larger percentage of the ore, however, is shipped to eastern ports along Lake Erie, which are near the coal fields and thus are able to obtain the fuel at less cost.

Pig iron is the raw material from which all steel and various grades of iron are made. In all branches of industry steel is daily coming into greater prominence and demands a larger supply of the raw material, hence the fundamental importance of the iron ore mines, both to Michigan and to the welfare of our country.

COAL.

Roughly speaking, the process of mining coal consists in digging and caving down the coal from the coal beds and hauling the broken fragments to the surface, from whence they are transported directly to the consumer. The chief difficulty in mining coal beds lies in propping up the overlying strata during the operation of extracting the coal beneath, so that the mine will not cave in and thus bring disaster to the miners below. This end is attained by placing long blocks and logs of wood on end in the sides of the passageway and across the top, in such a way that they are able to withstand the strain of superincumbent masses above, (timbering). This same method of timbering is employed in the iron mines and copper mines. In the course of time the timbers decay and must be replaced by new ones. Timbering is an unavoidable expense in all classes of mining. In all mining operations the object in view is to get the raw material, the ore, out of the ground and

through the smelters to the consumer in the cheapest way possible. The best engineer is he who under given conditions is able to produce the ore most economically and with the simplest means.

It is a fascinating sight to observe the miners as they emerge from the cage out of the dark depths of the mine to daylight, covered with the grime of their labors. Hurriedly they rush to the "dry" to wash and change, only to reappear in a short time as ordinary citizens instead of workers of the deep. They wrest from the depths of the earth the riches which have been lying there for ages, awaiting the quickening touch of man to make them useful and subservient to his desires.